New perspectives on volcanic clouds from the A-Train

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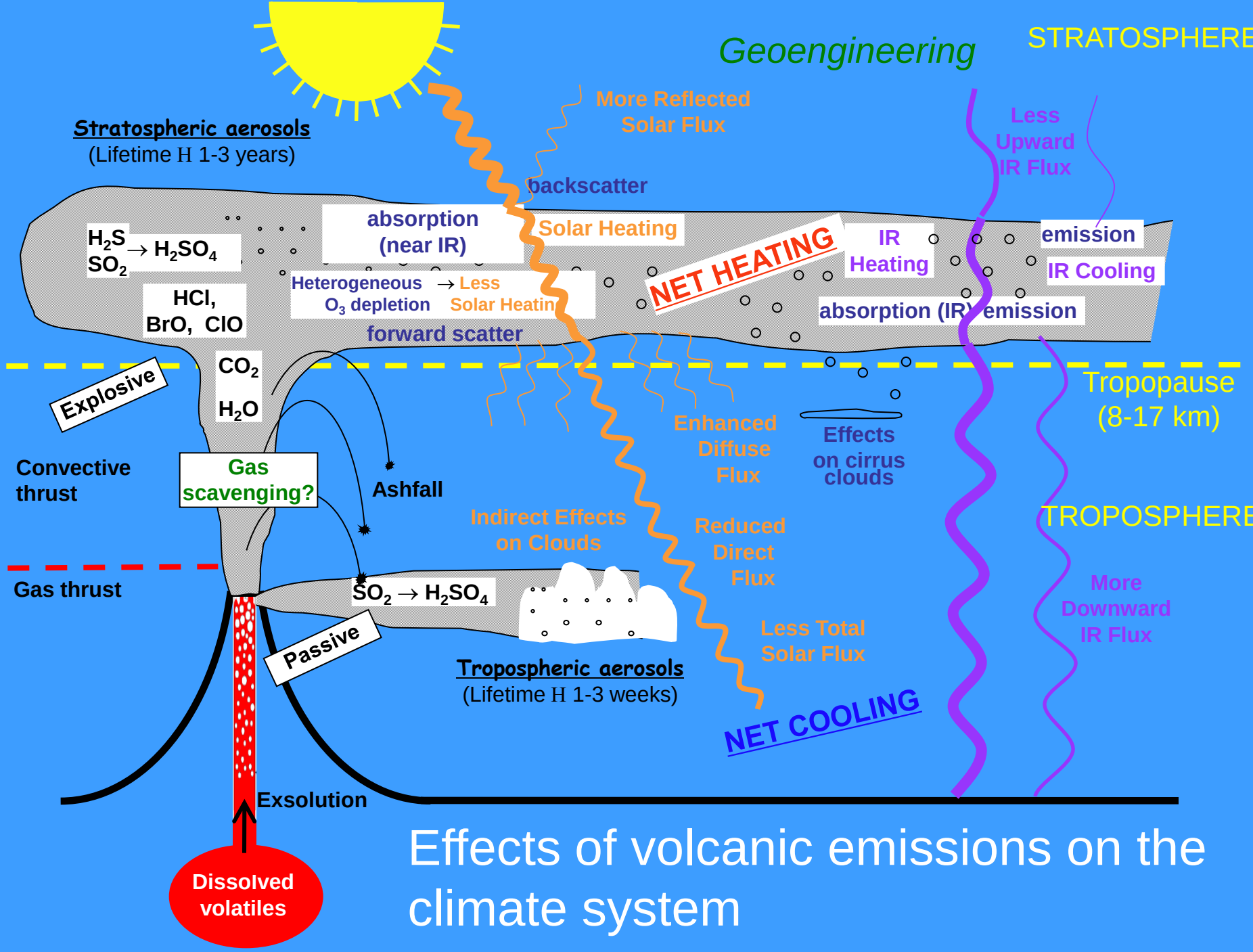
Michigan Tech
Create the Future

Volcanic clouds: ‘dirty thunderstoms’

- Volcanic eruption cloud
  - Vertically extensive
  - Short-lived (hours)
  - Overshooting top
  - Stratospheric penetration
  - Lightning
  - Umbrella cloud (gravity current)
  - ‘Overseeded’ with ice nuclei (ash)
  - Ash (µm – cm), hydrometeors
  - Layered structure
  - ‘Downdraft’ during ashfall?

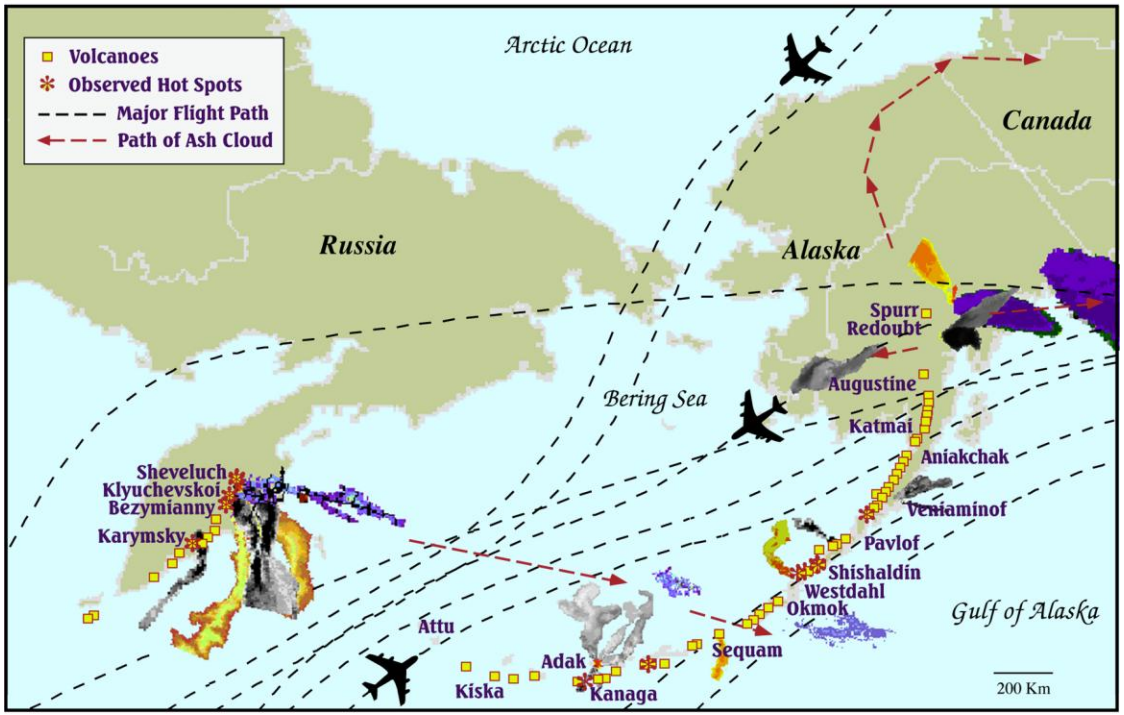
Redoubt, AK, April 21, 1990

- Single-cell Cb
  - Vertically extensive
  - Short-lived (hours)
  - Overshooting top
  - Rise to tropopause
  - Anvil: ice-rich blow-off
  - Hydrometeors (rain – hail)
  - Lightning
  - Downdrafts

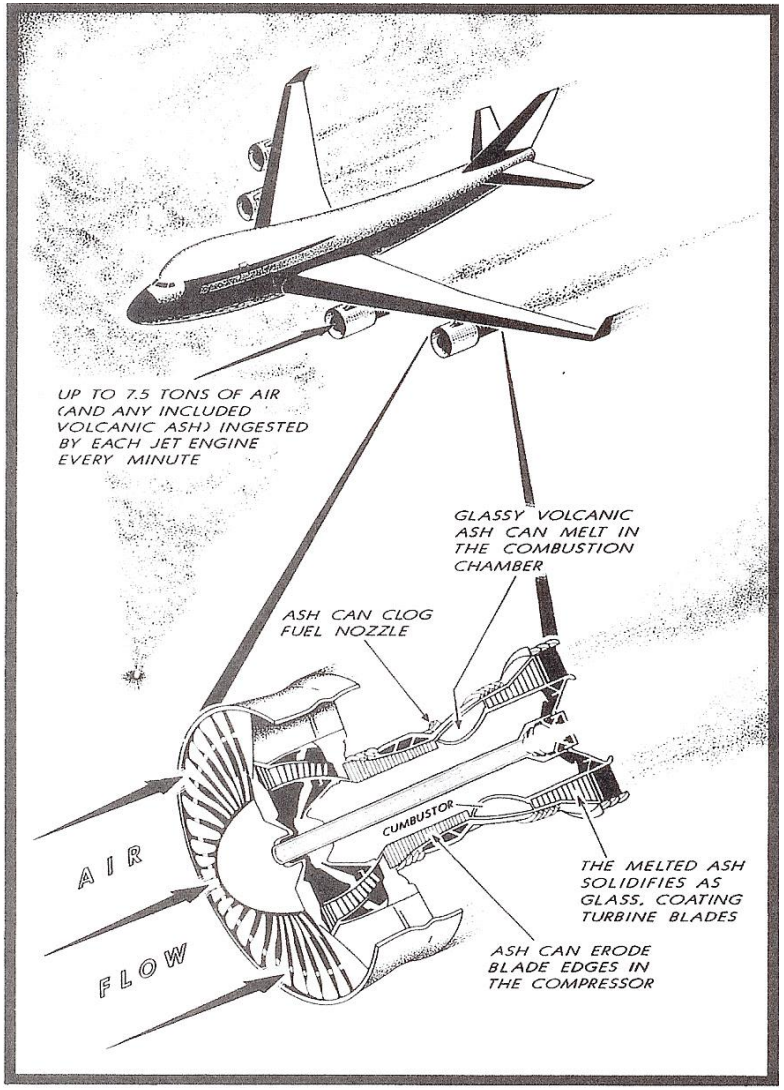


Effects of volcanic emissions on the climate system

Aviation hazards from volcanic clouds

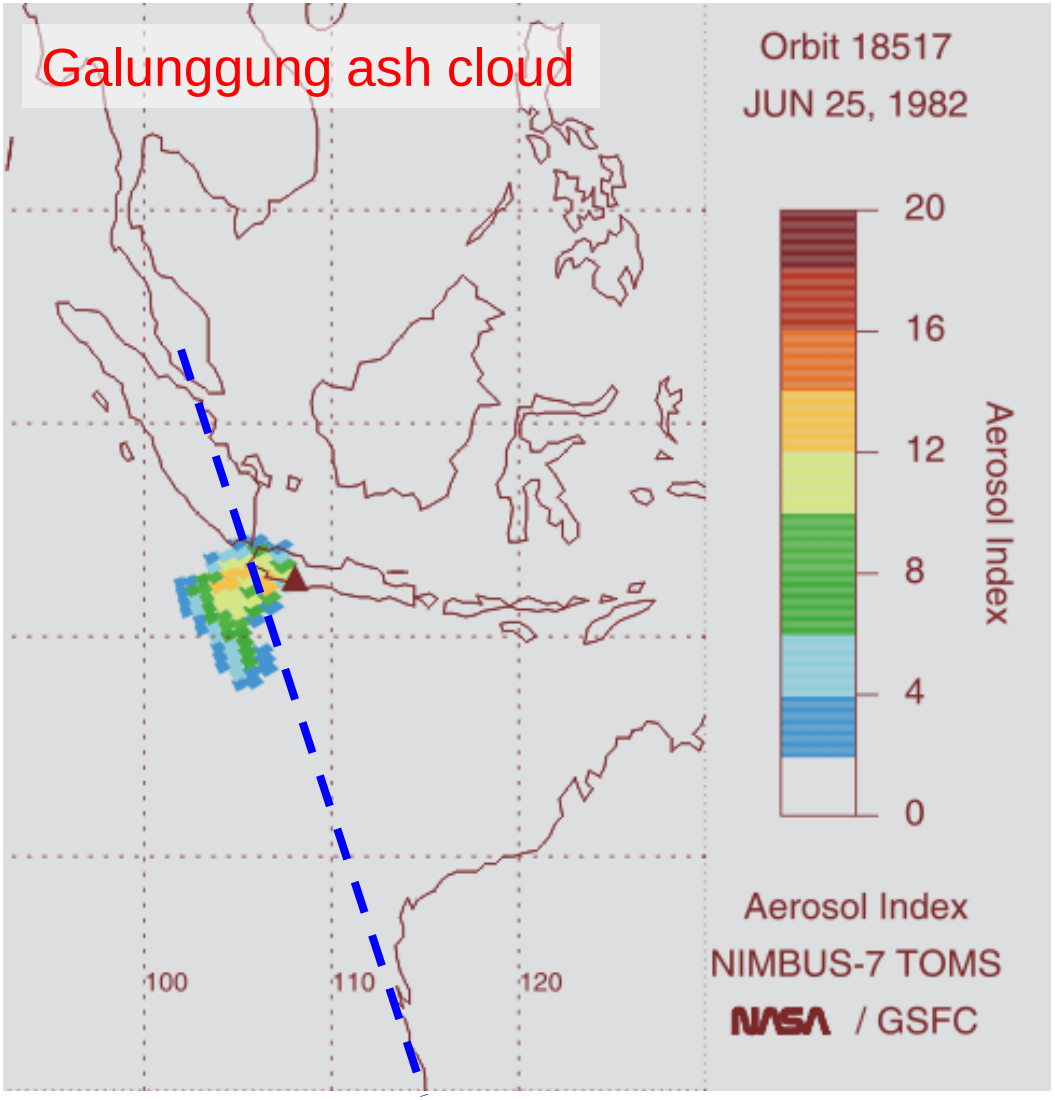


- Acute hazards
  - Engine failure due to melted ash
  - Abrasion of windshield
  - Effects on avionics
- Secondary hazards
  - Corrosion by ash, sulfuric acid
- Mitigation
  - Immediate detection of fresh volcanic clouds
  - Tracking/forecast of cloud position and altitude



From: Volcanoes; Crucibles of Change, Princeton U. Press, Princeton, 1997.

Two near-disastrous volcanic cloud encounters



"Ladies and gentlemen, this is your captain speaking. We have a small problem. All four engines have stopped. We are doing our damnedest to get them under control. I trust you are not in too much distress." Capt. Eric Moody, BA Flight 9

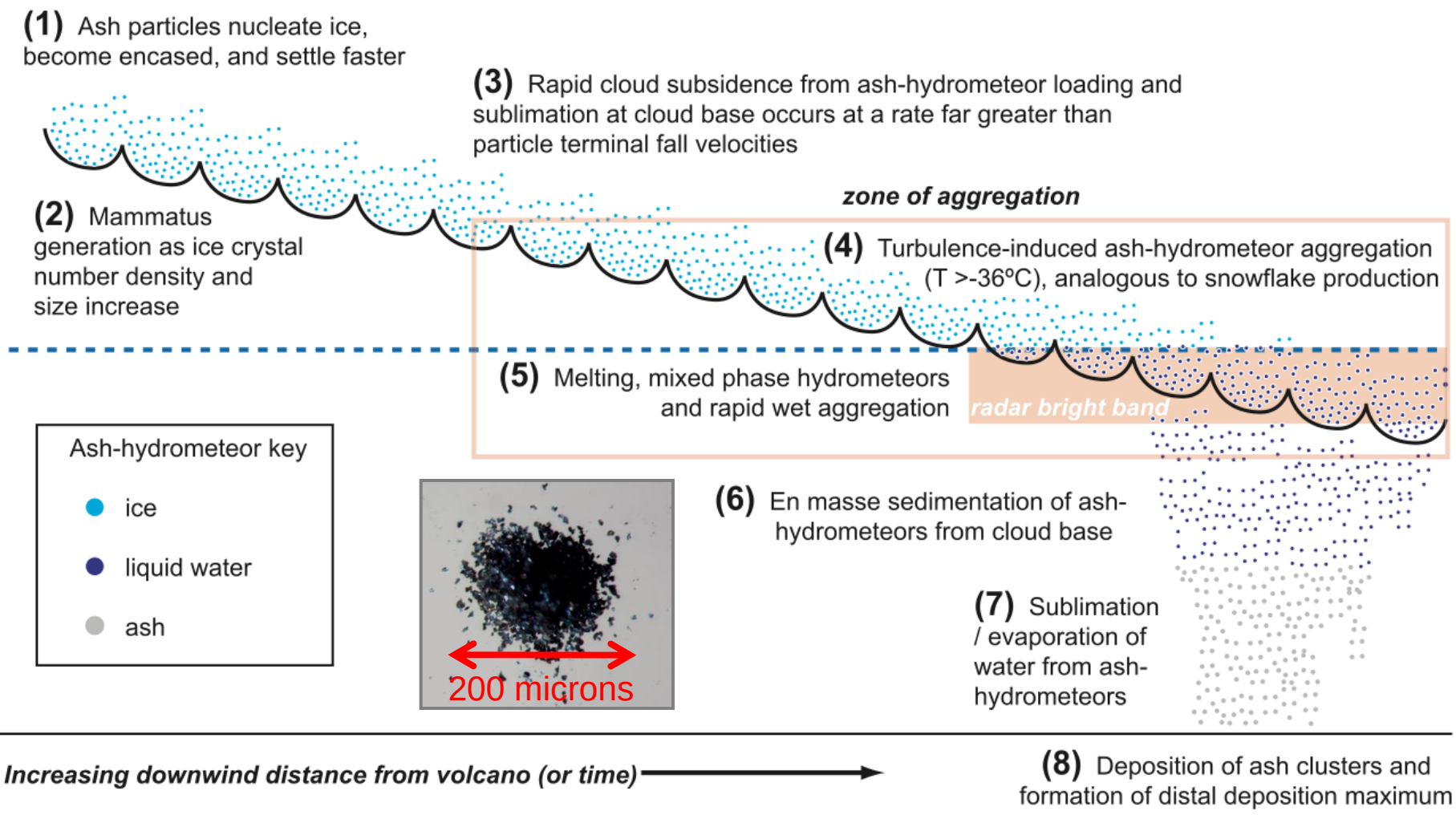
~2 g/m^3 ash?

- BA 009 (B747), Kuala Lumpur – Perth, 24 June 1982
- KLM 867 (B747), Amsterdam – Tokyo, 15 December 1989 (Redoubt, AK)

Volcanic ash sedimentation

Mammatus lobes on the Mount St. Helens volcanic cloud over Ephrata, WA, 18 May 1980
(© D. Miller)

Hydrometeor-enhanced sedimentation of volcanic ash



- Ash aggregation prematurely removes fine ash that would be an aviation hazard
- How do we explain secondary ash thickness maxima and ash aggregate fallout?
- Can CloudSat W-band radar detect the bright band?

[Durant et al., JGR, 2009]

Exploiting A-Train synergy for volcanic cloud studies

Aura

OMI - SO_2, ash, BrO

TES - SO_2

MLS - UTLS SO_2, HCl, IWC

Aqua

MODIS - SO_2, ash, sulfate, ice

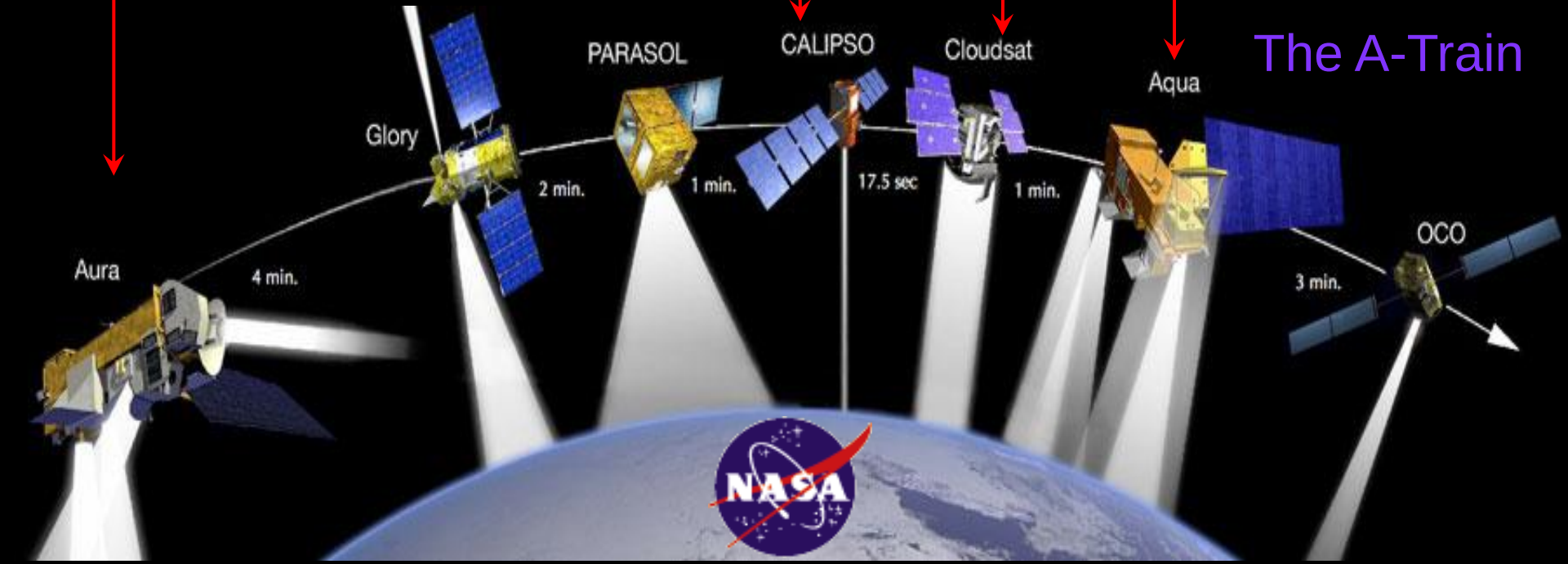
AIRS - SO_2, ash, sulfate, ice, SO_2 profile

CloudSat

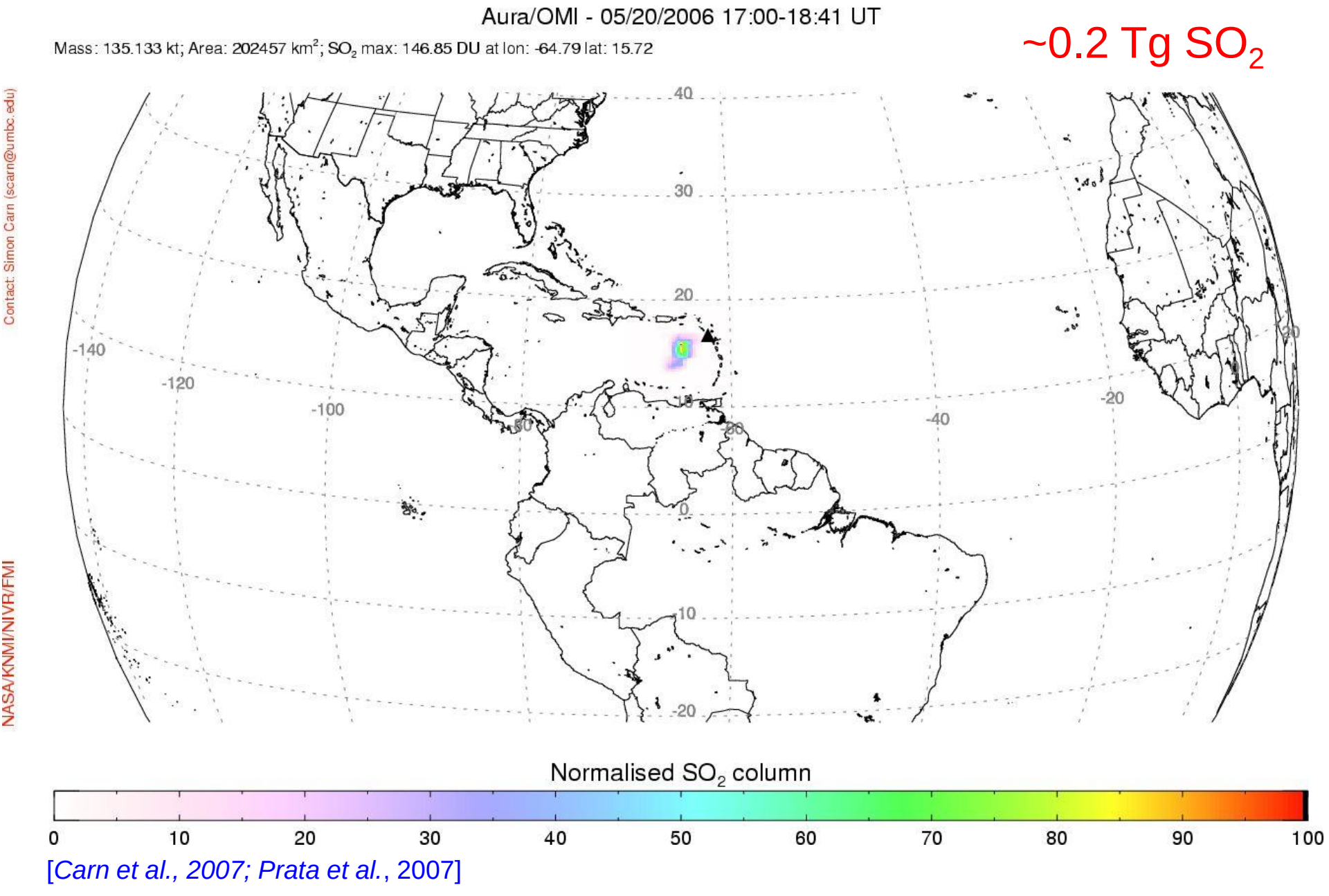
CPR – precipitation, hydrometeors

CALIPSO

CALIOP - aerosol altitude, phase/type



Soufrière Hills volcano (Montserrat) eruption, May 2006



[*Carn et al., 2007; Prata et al.*, 2007]

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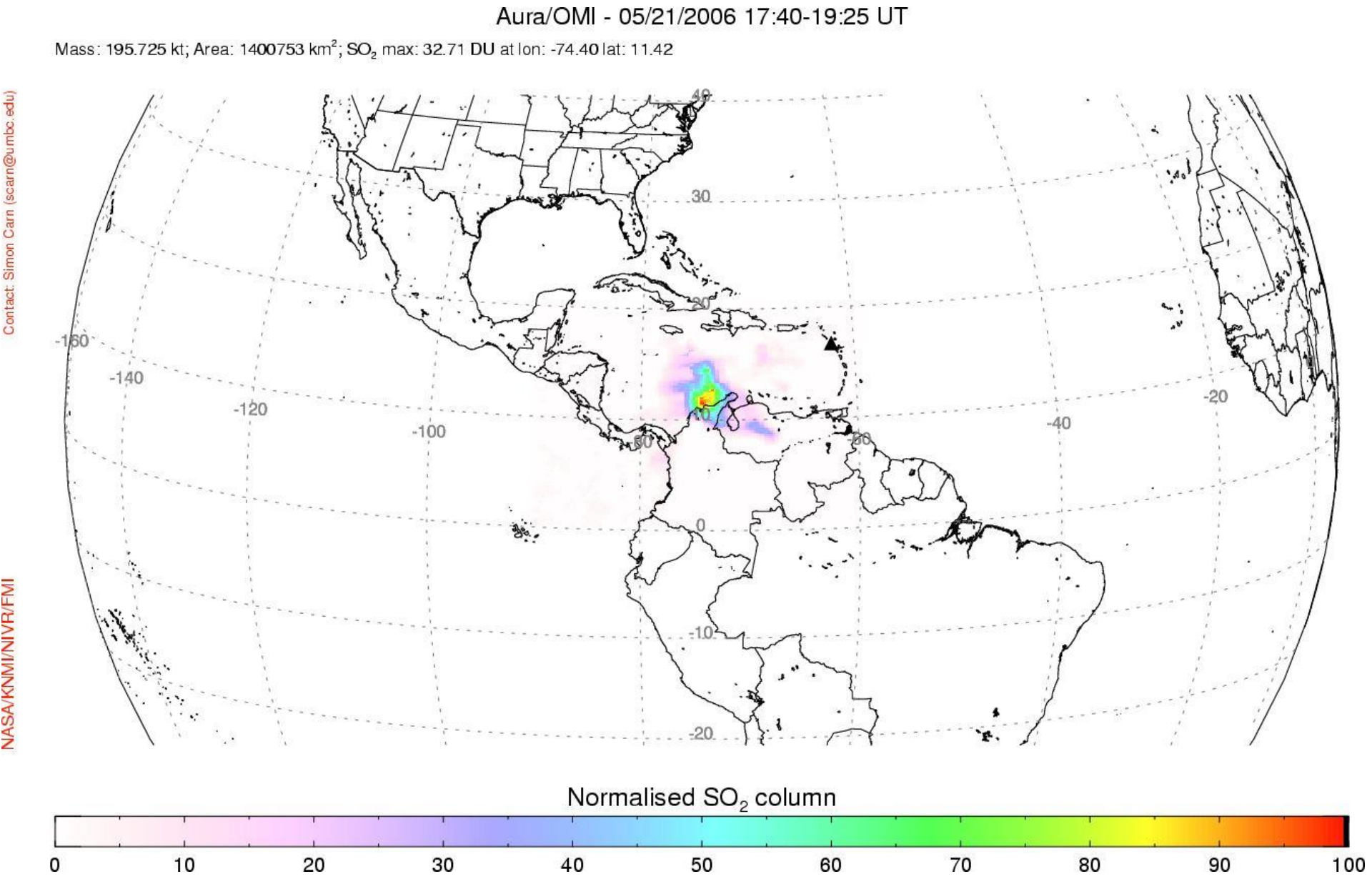

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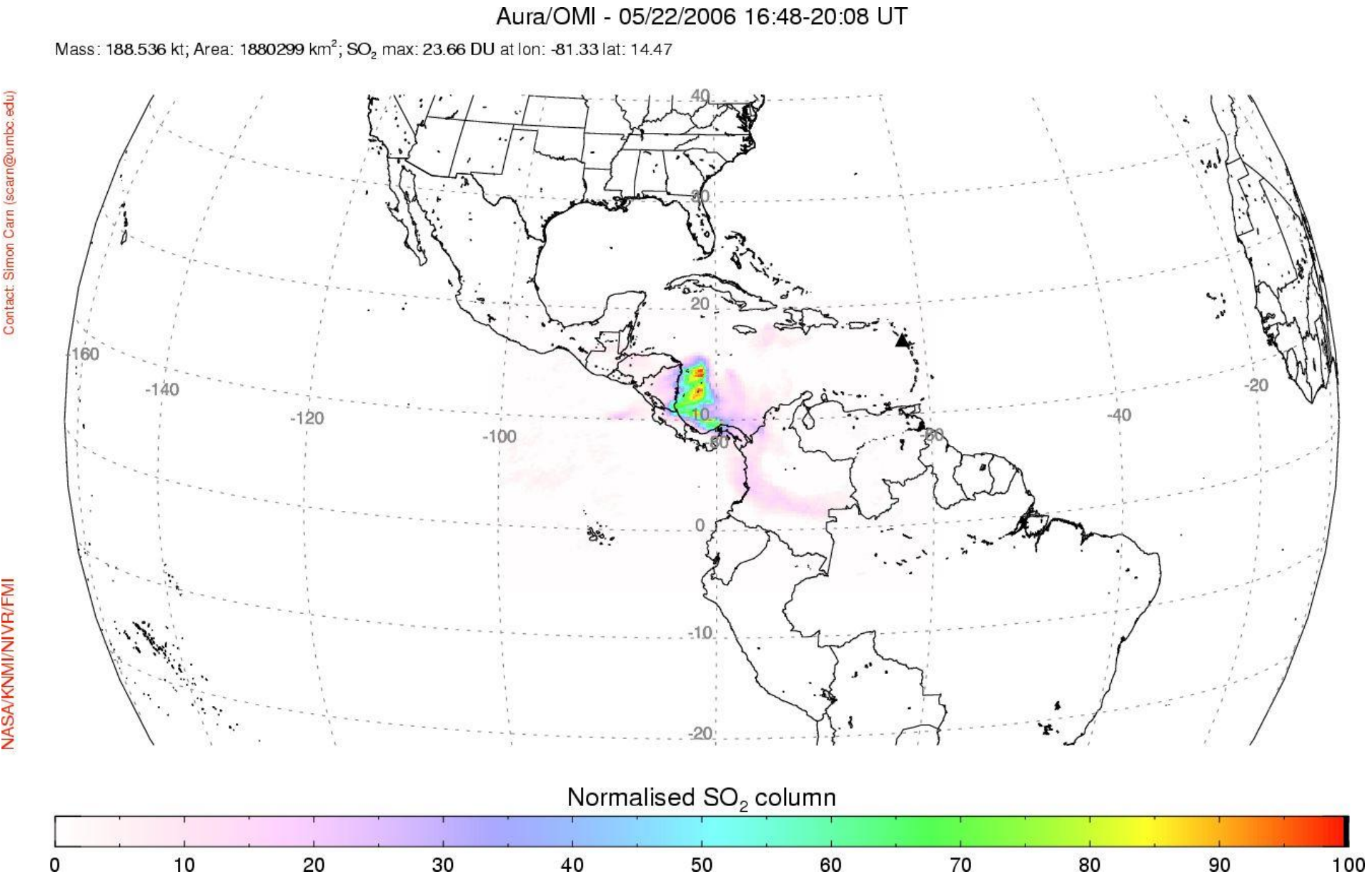

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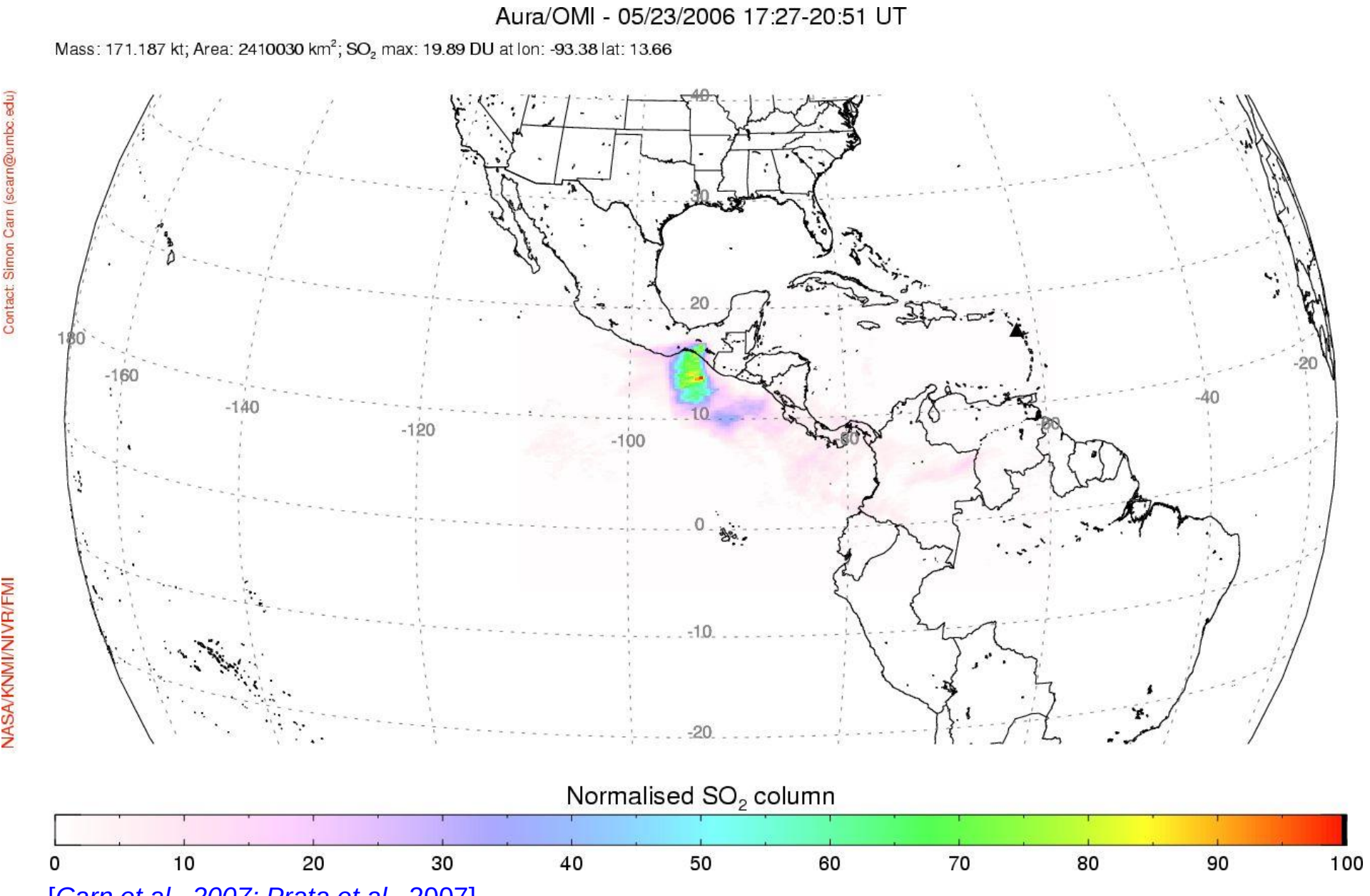

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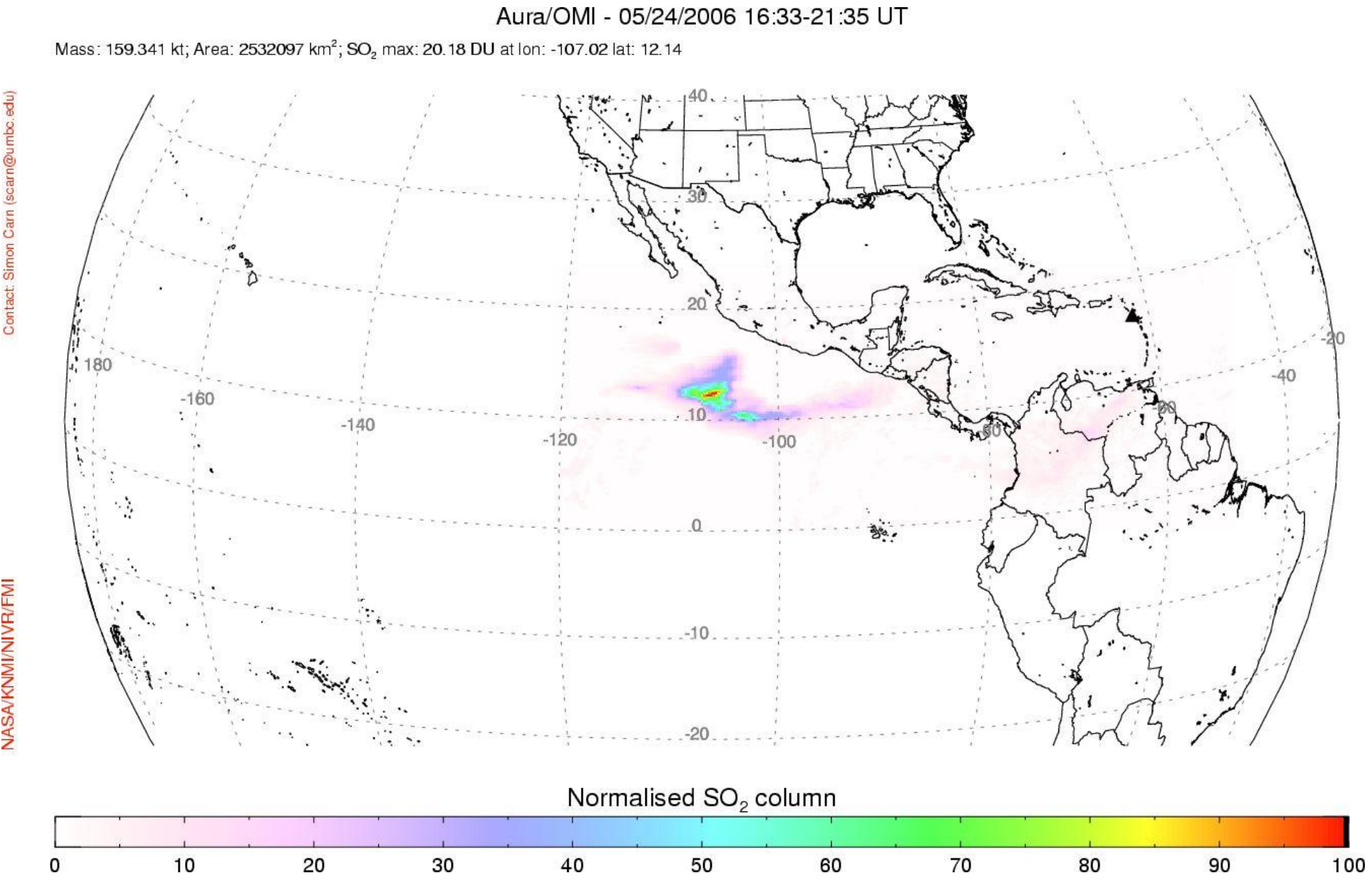

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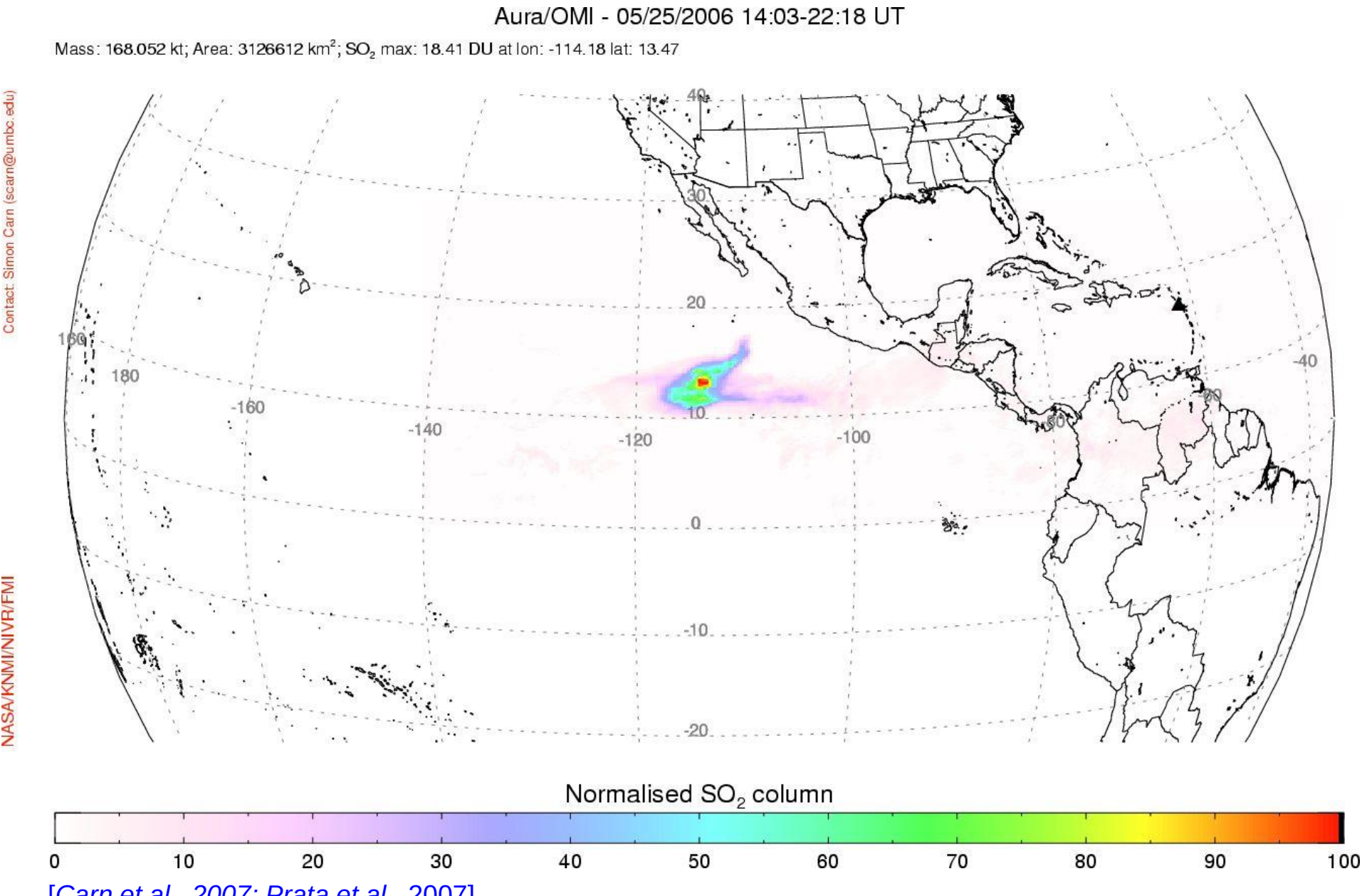

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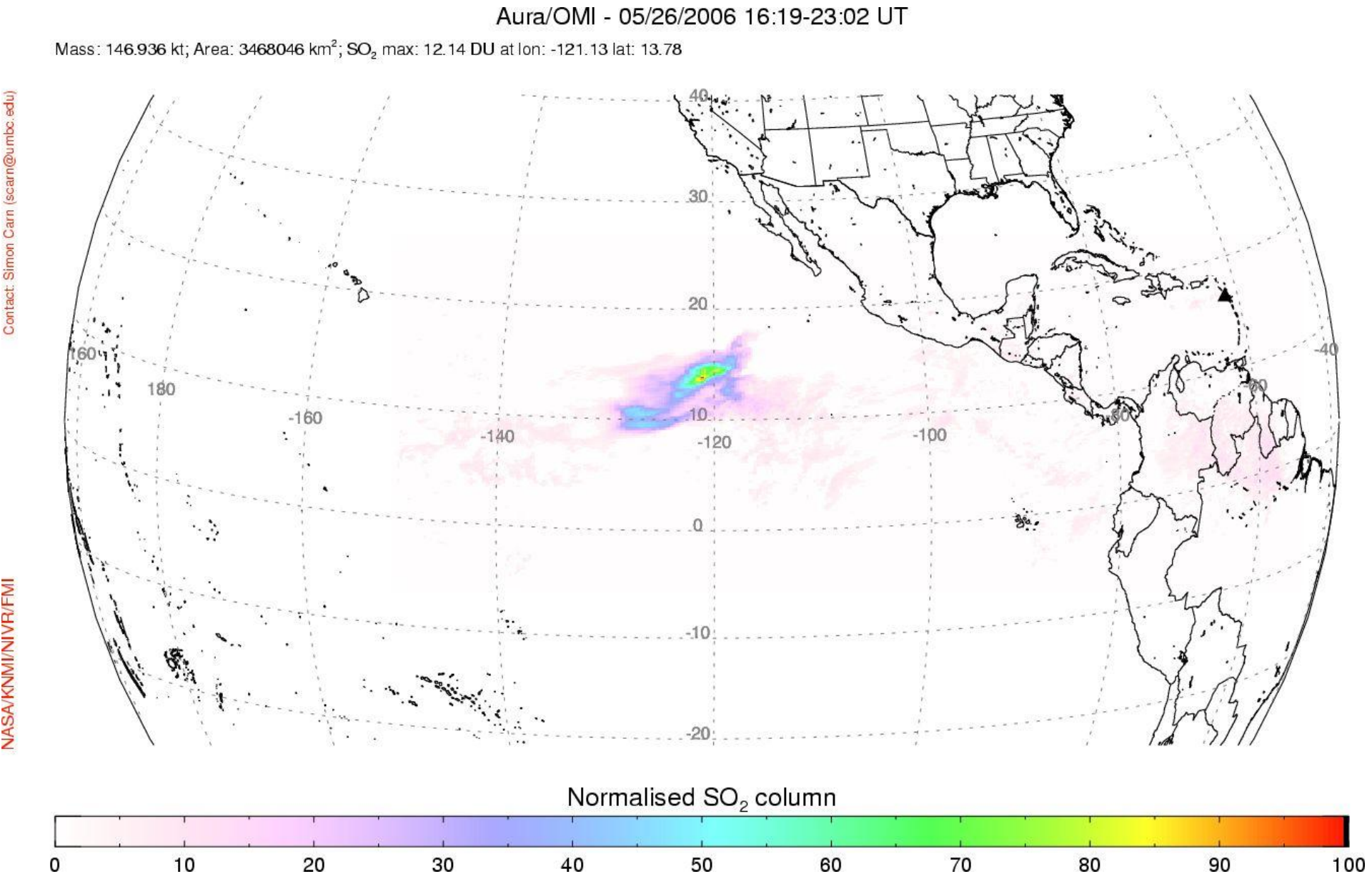

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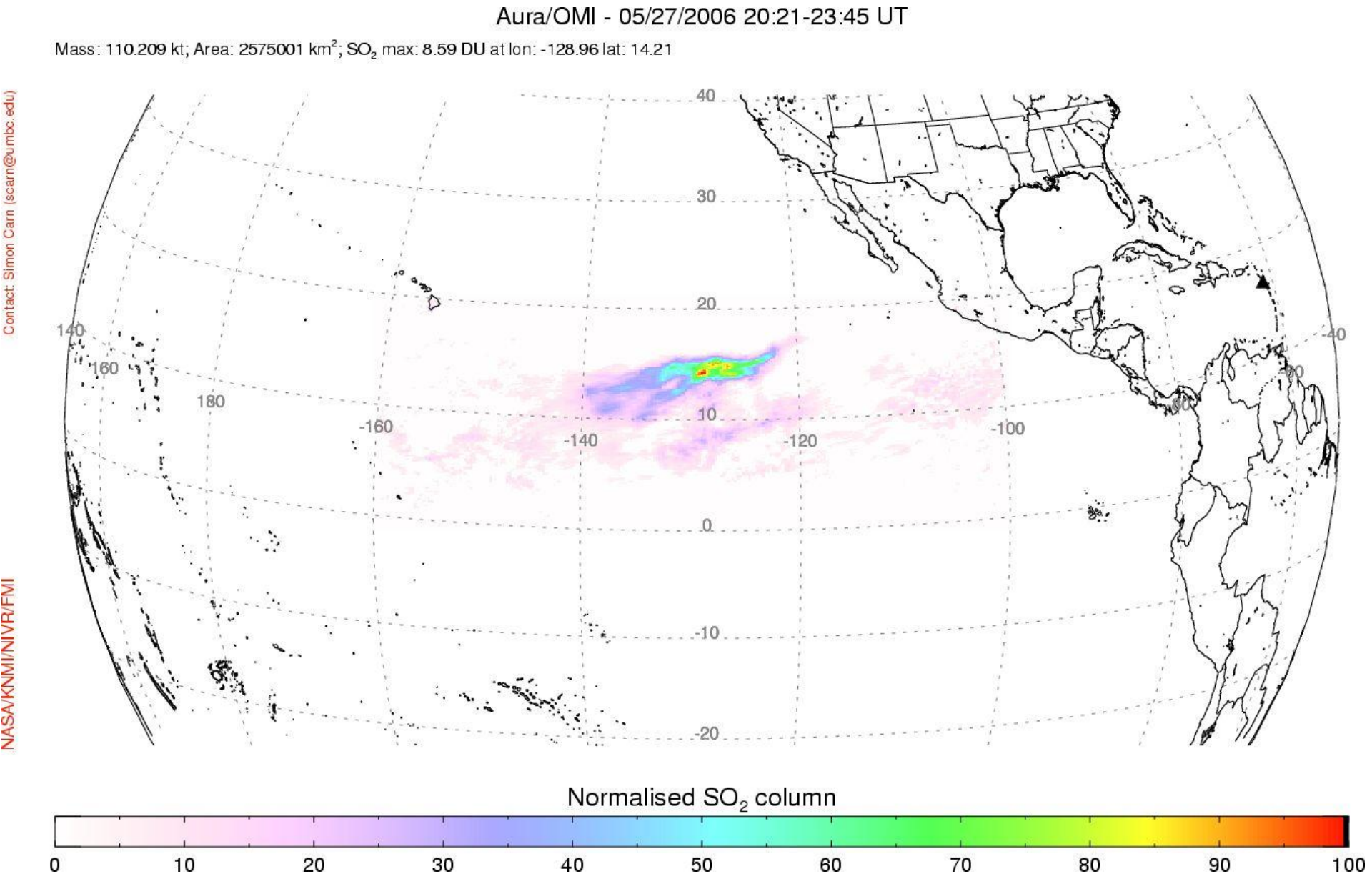

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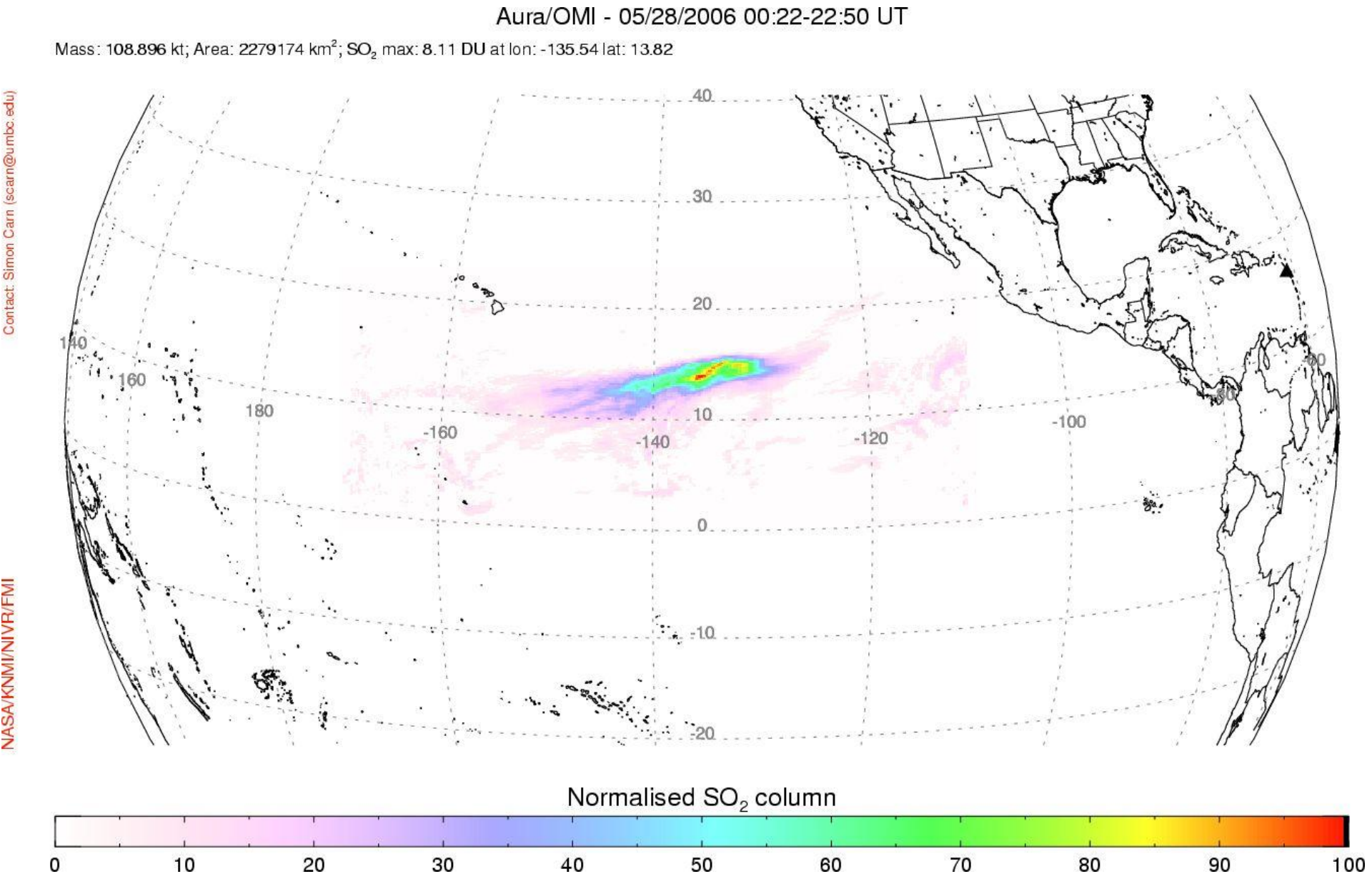

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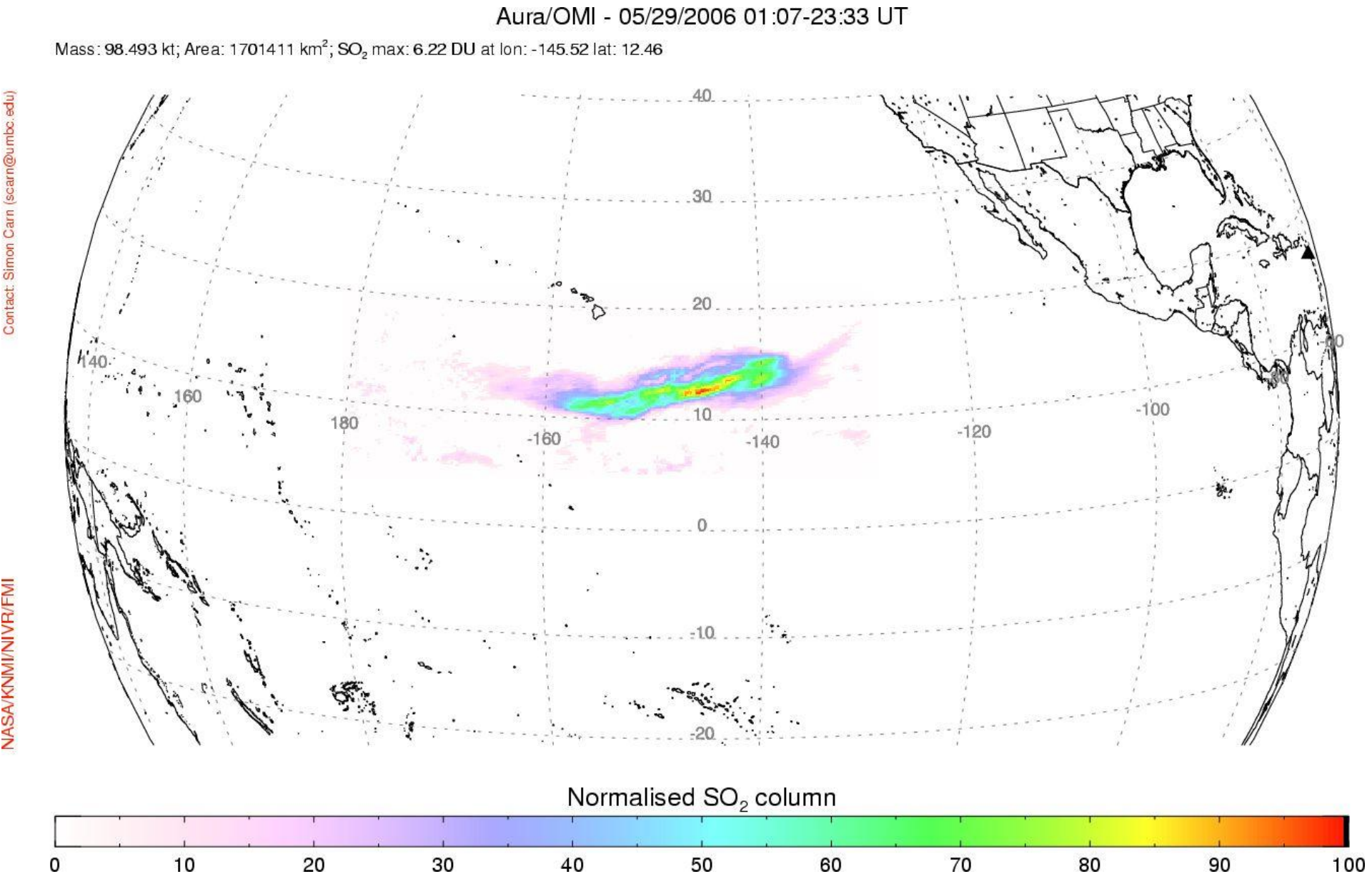

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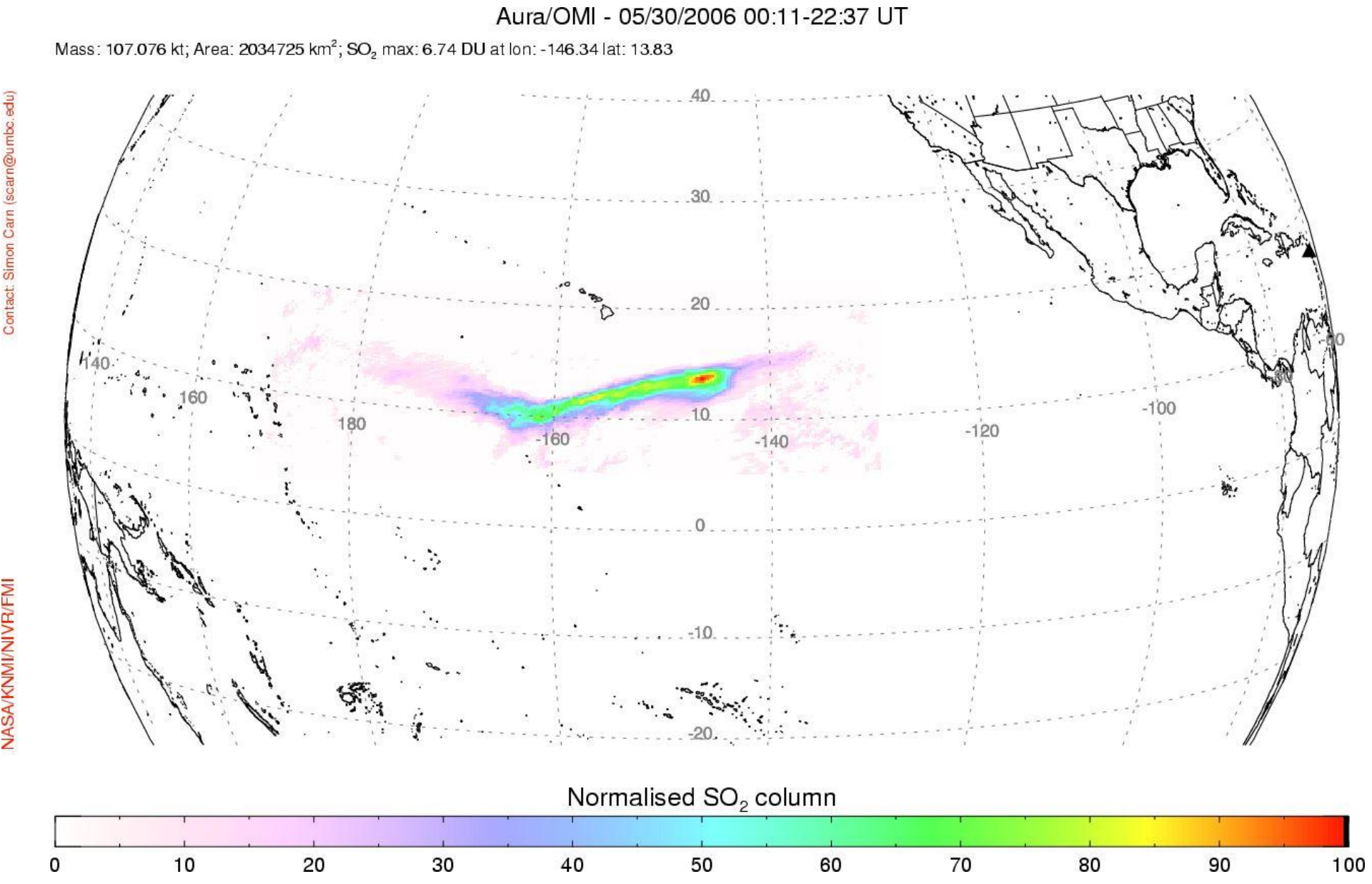

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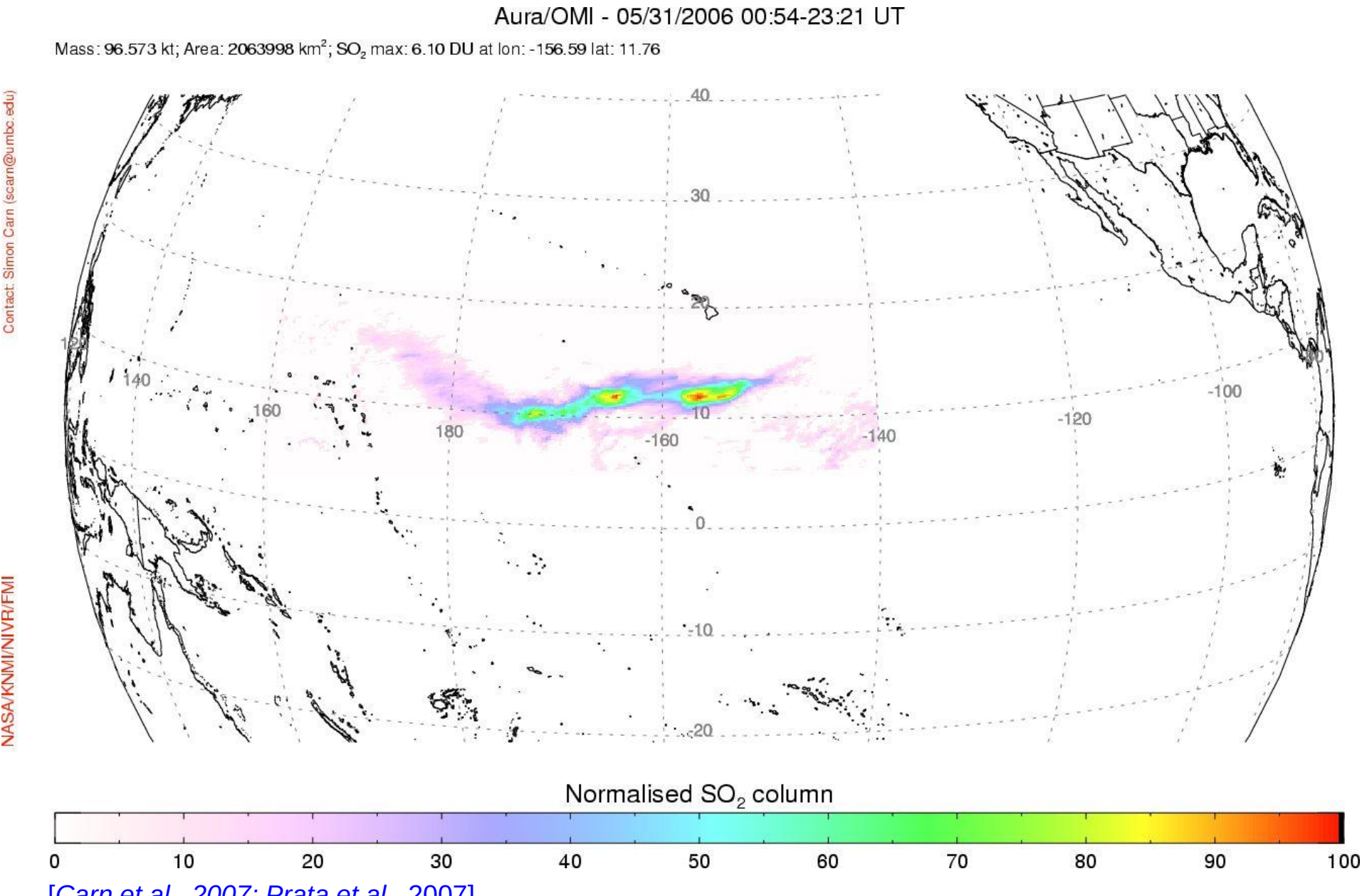

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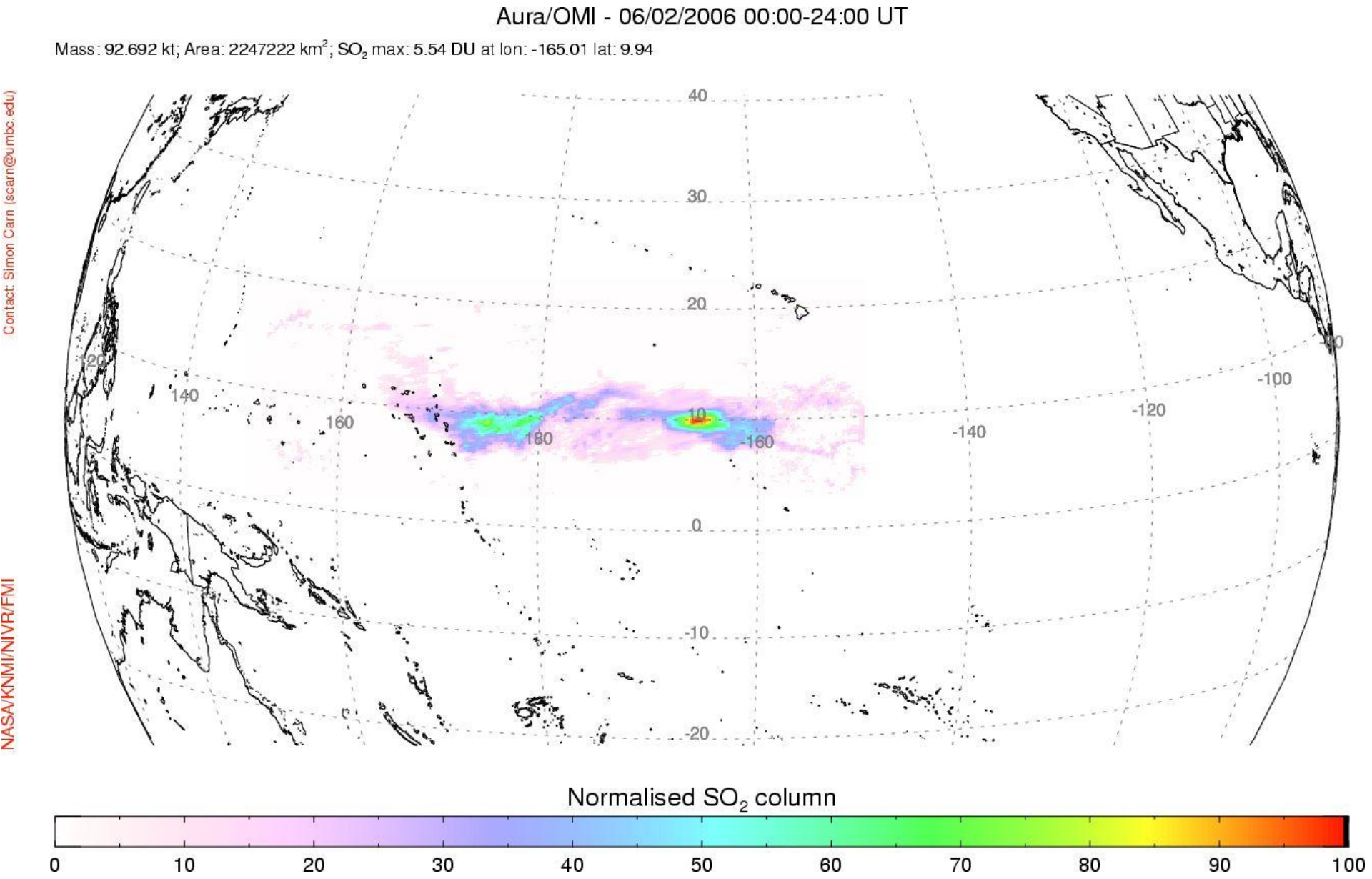

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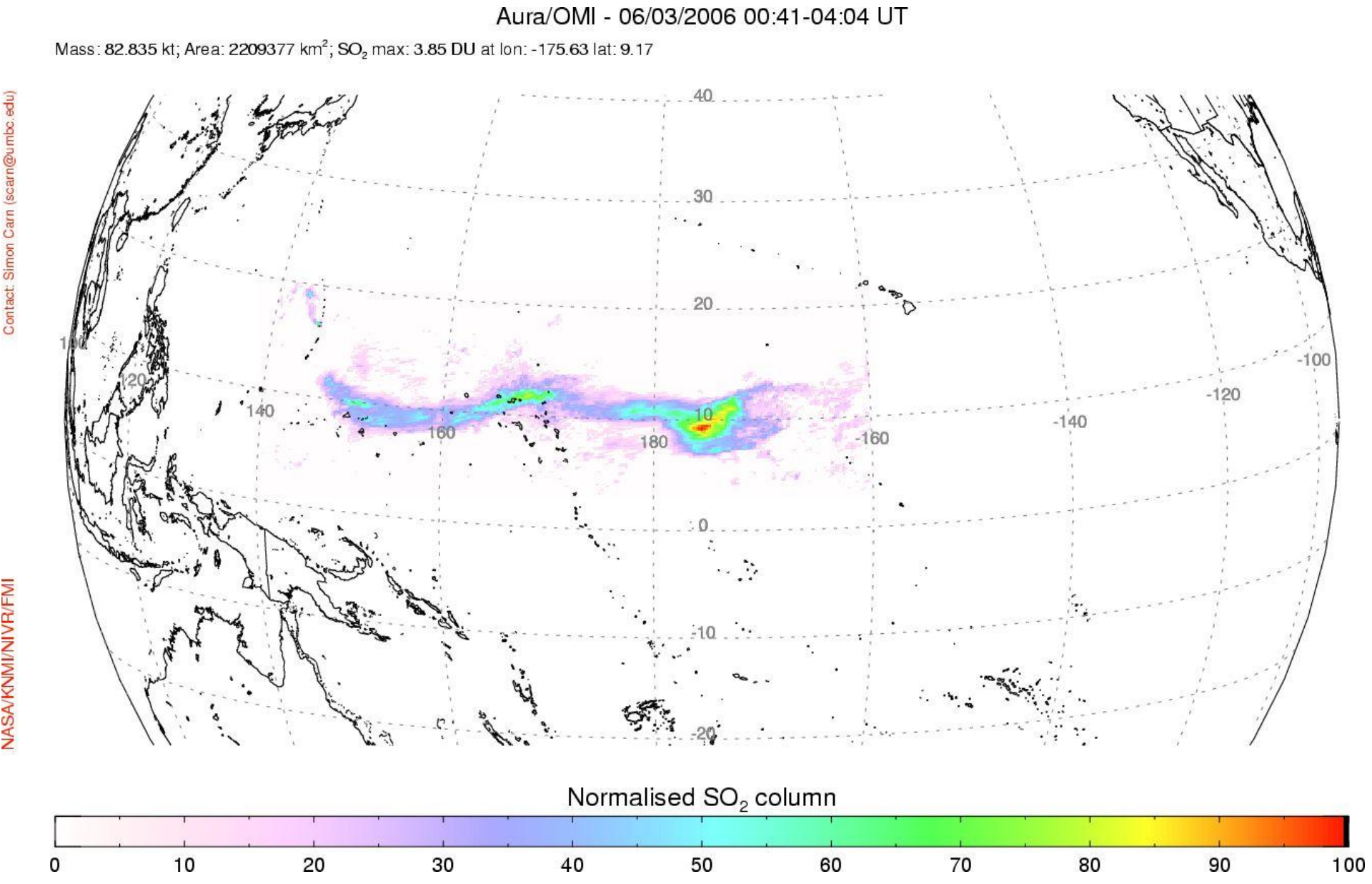

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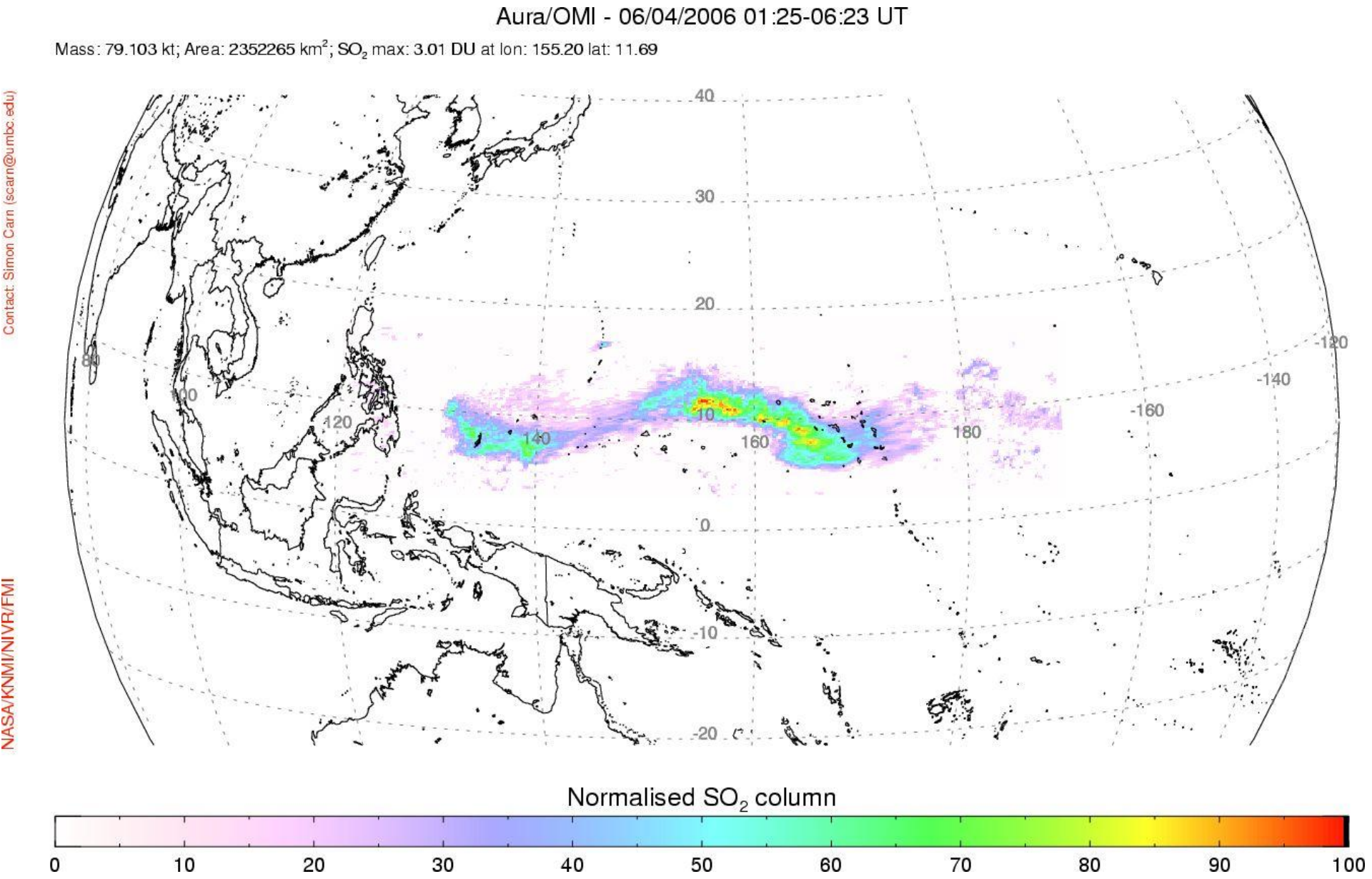

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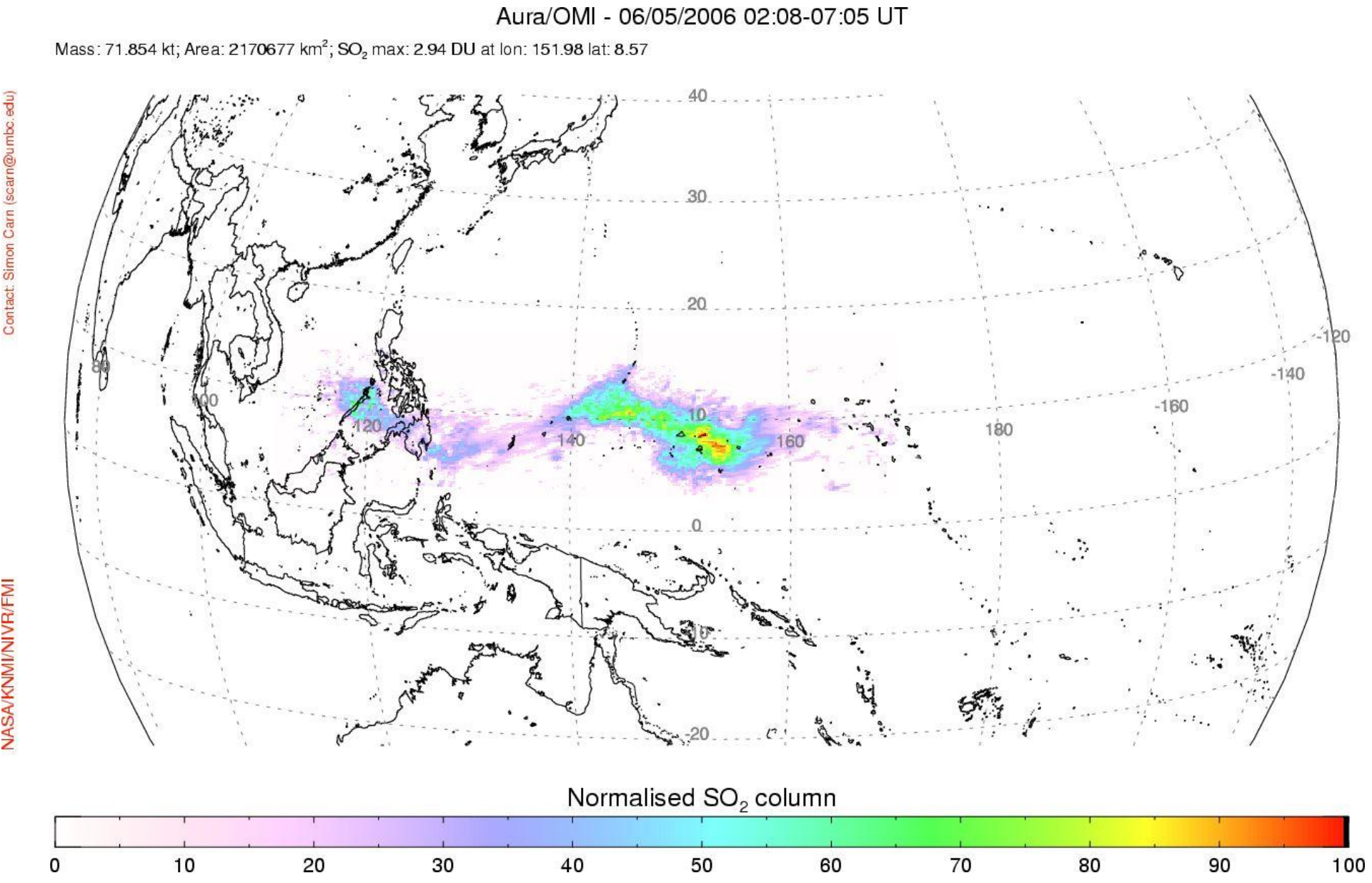

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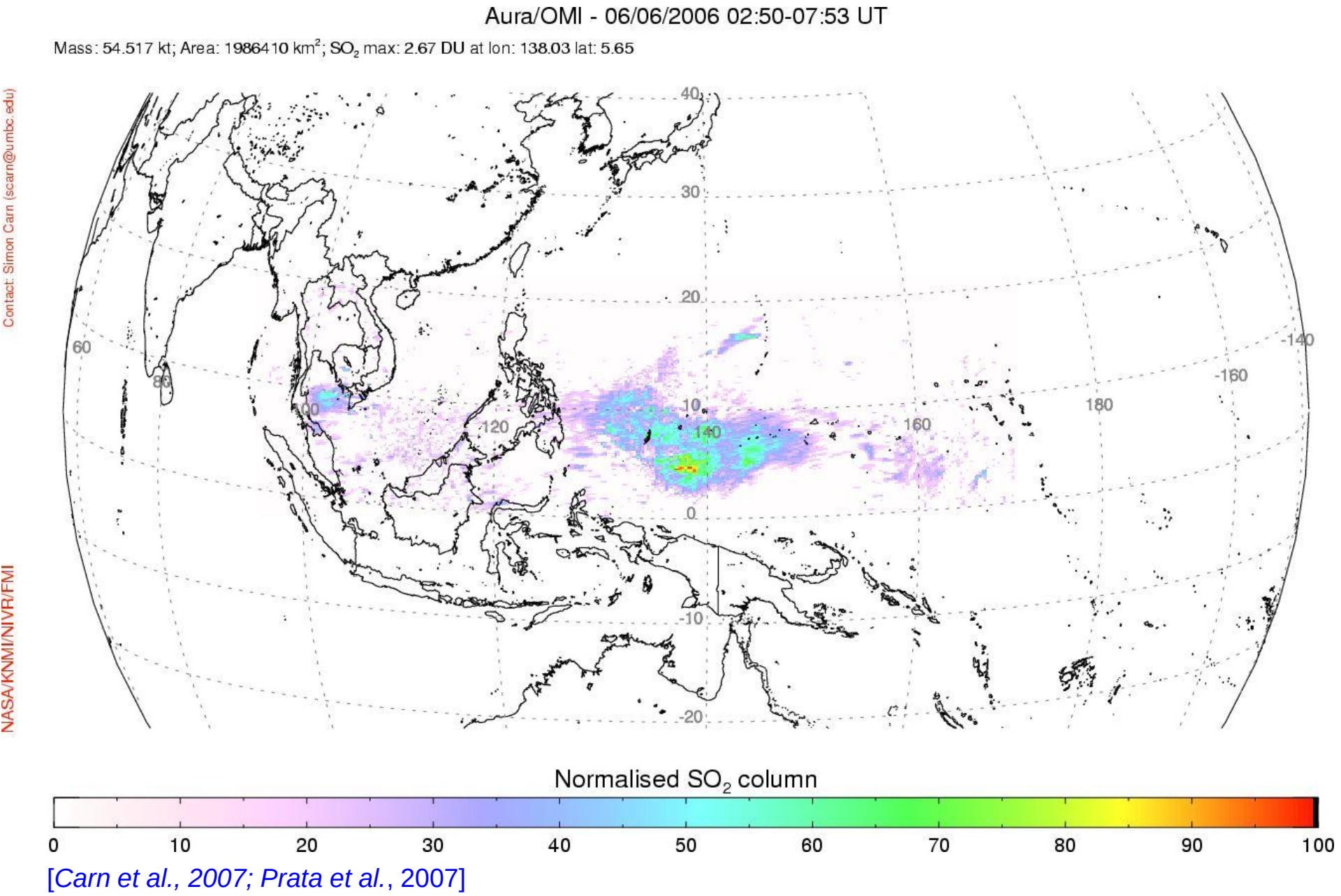

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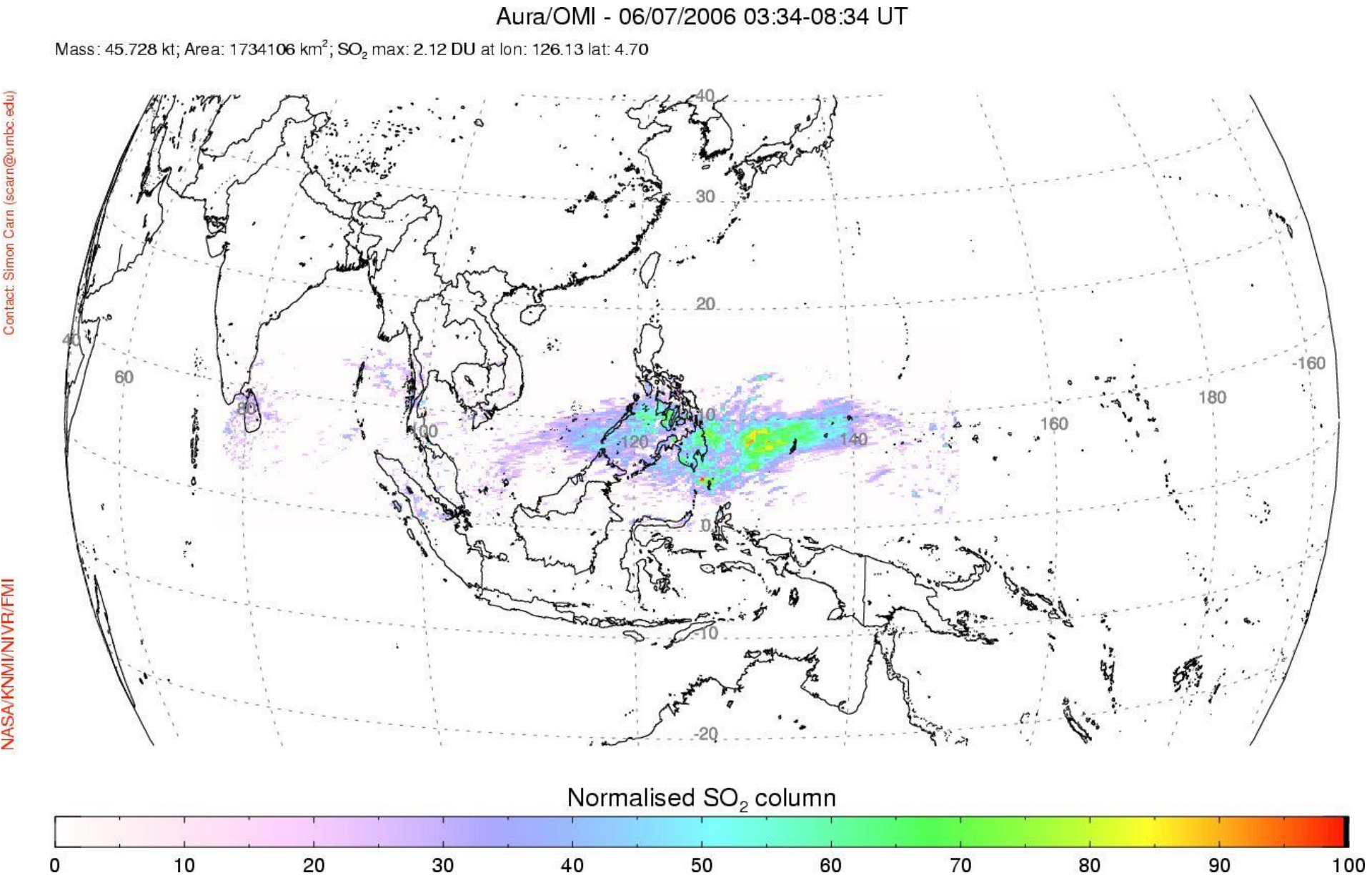

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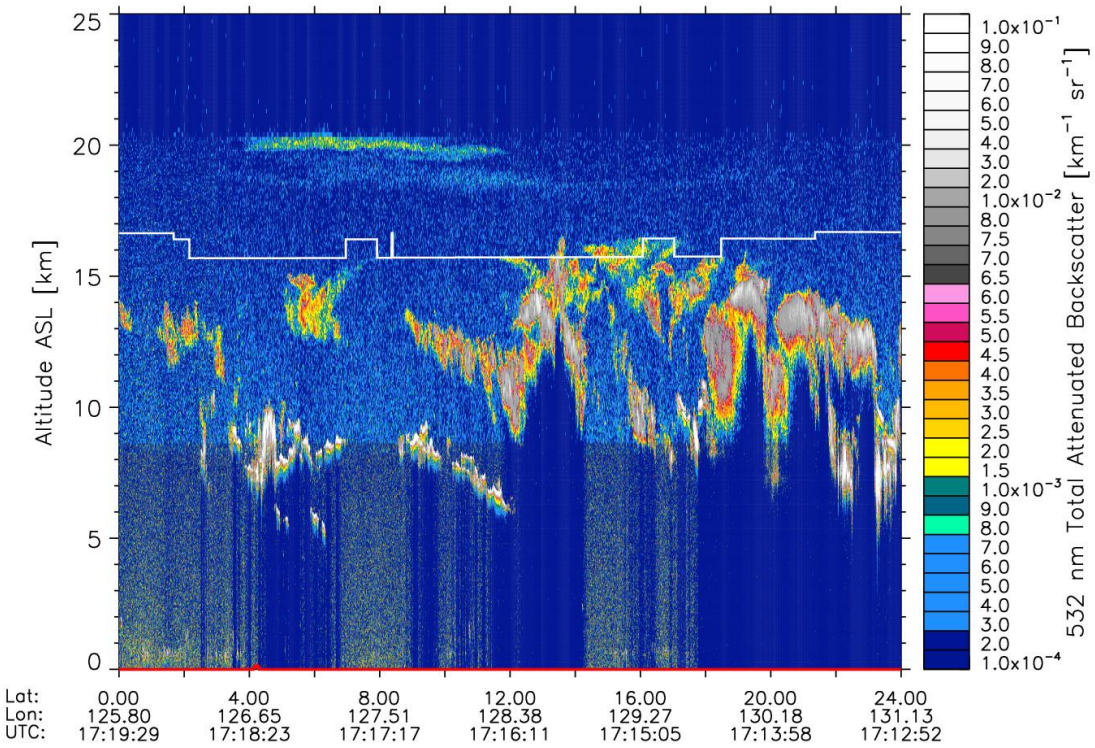
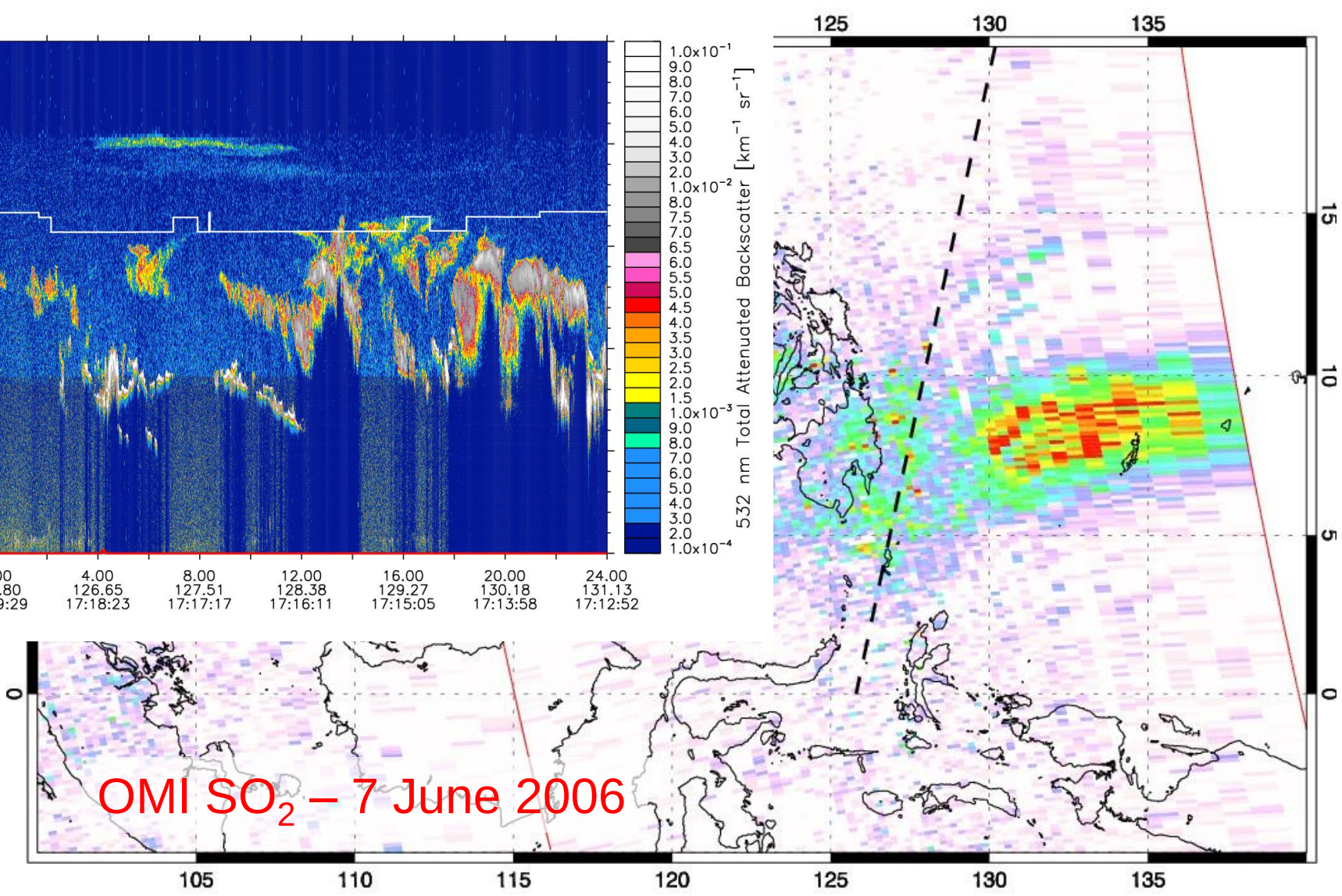
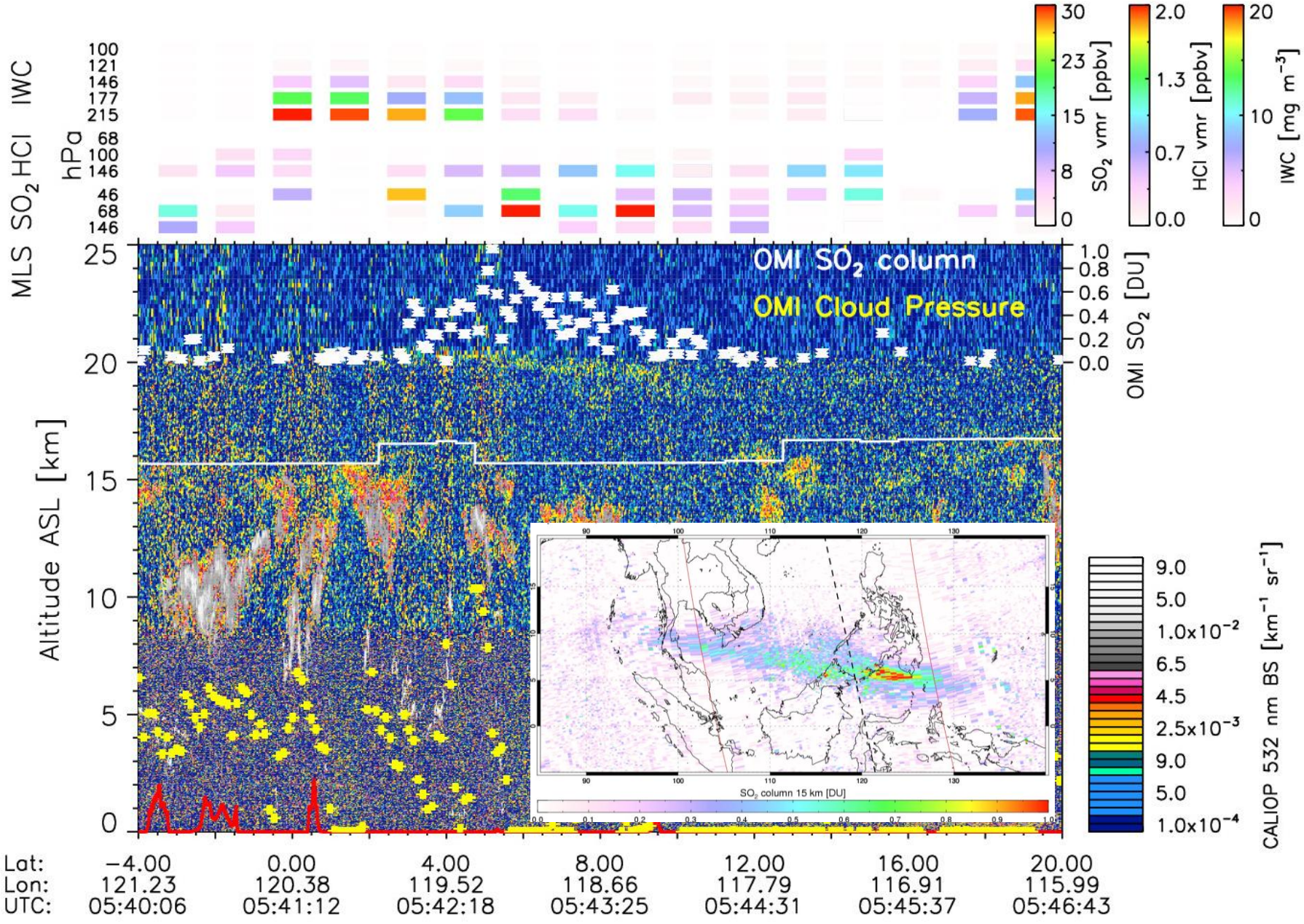
CALIPSO first light – 7 June 2006



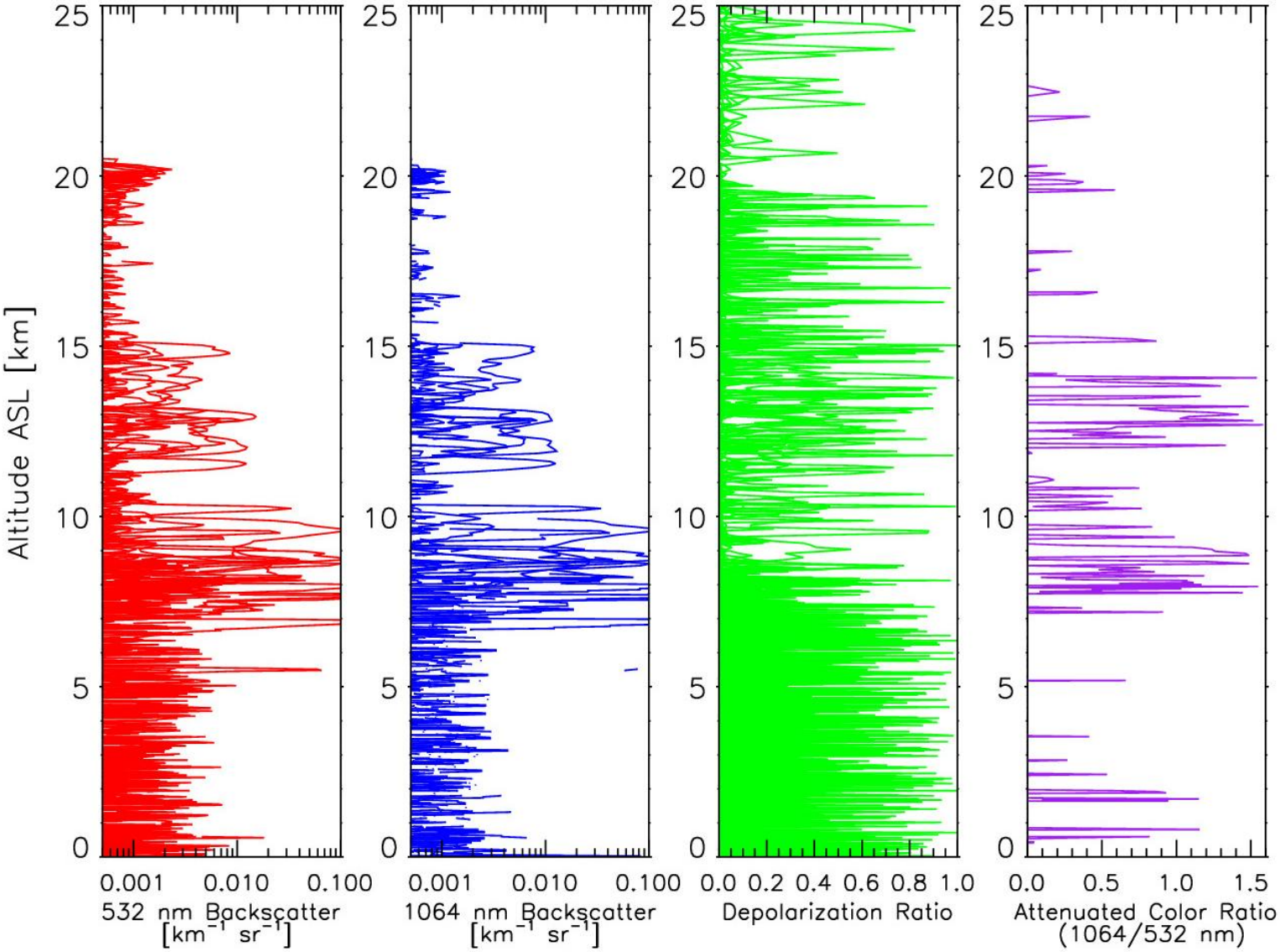


OMI SO_2 – 7 June 2006

CALIPSO – OMI – MLS: 8 June 2006



CALIPSO profiles through SHV aerosol cloud



- Aerosol layer non-depolarizing
- Liquid sulfate aerosol dominant

The 2010 eruption of Eyjafjallajökull (Iceland)

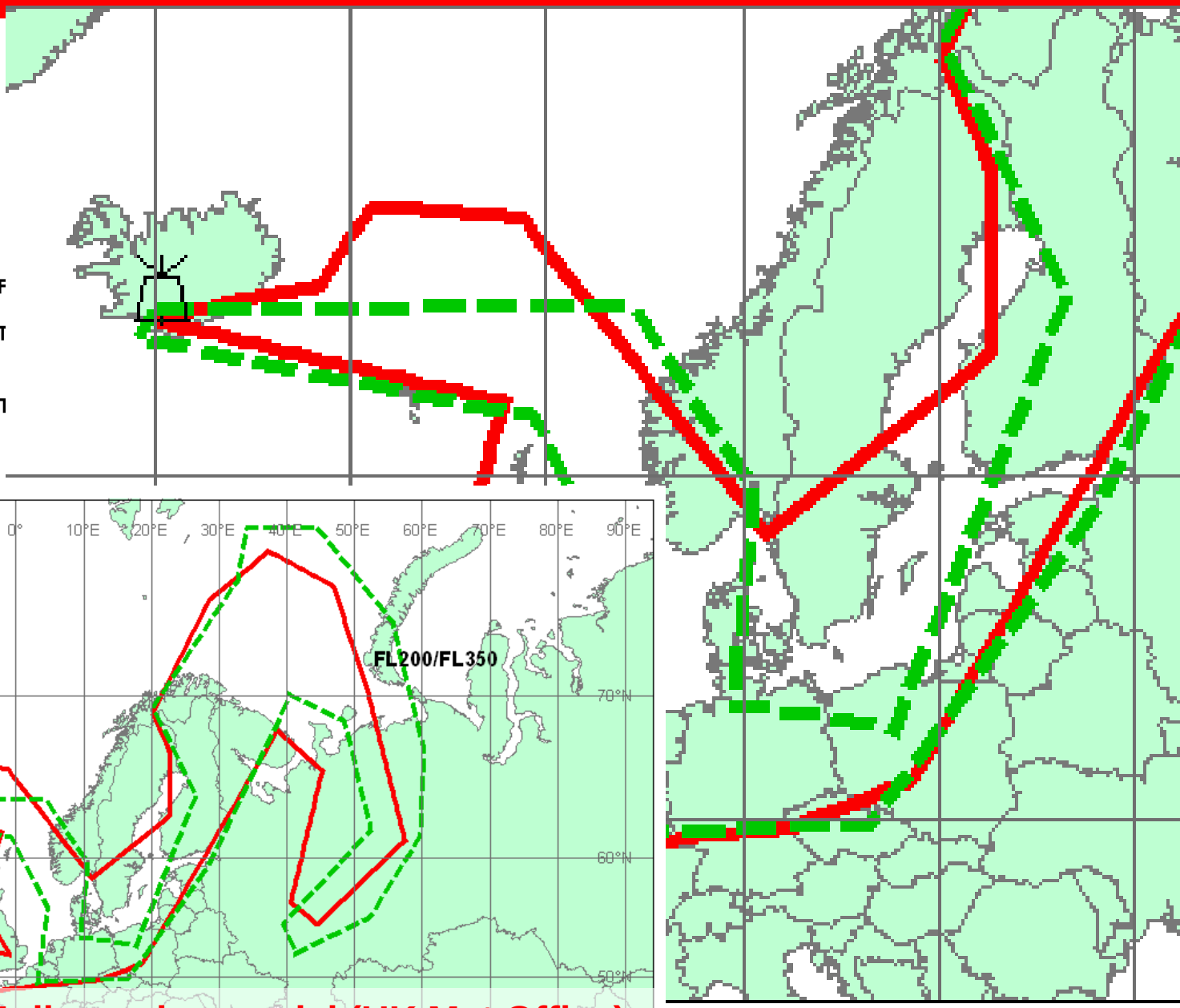
- High density of air routes
- Unusual wind direction
- Small volcanic ash particles
- No constraints on ‘safe’ concentration of ash for aircraft

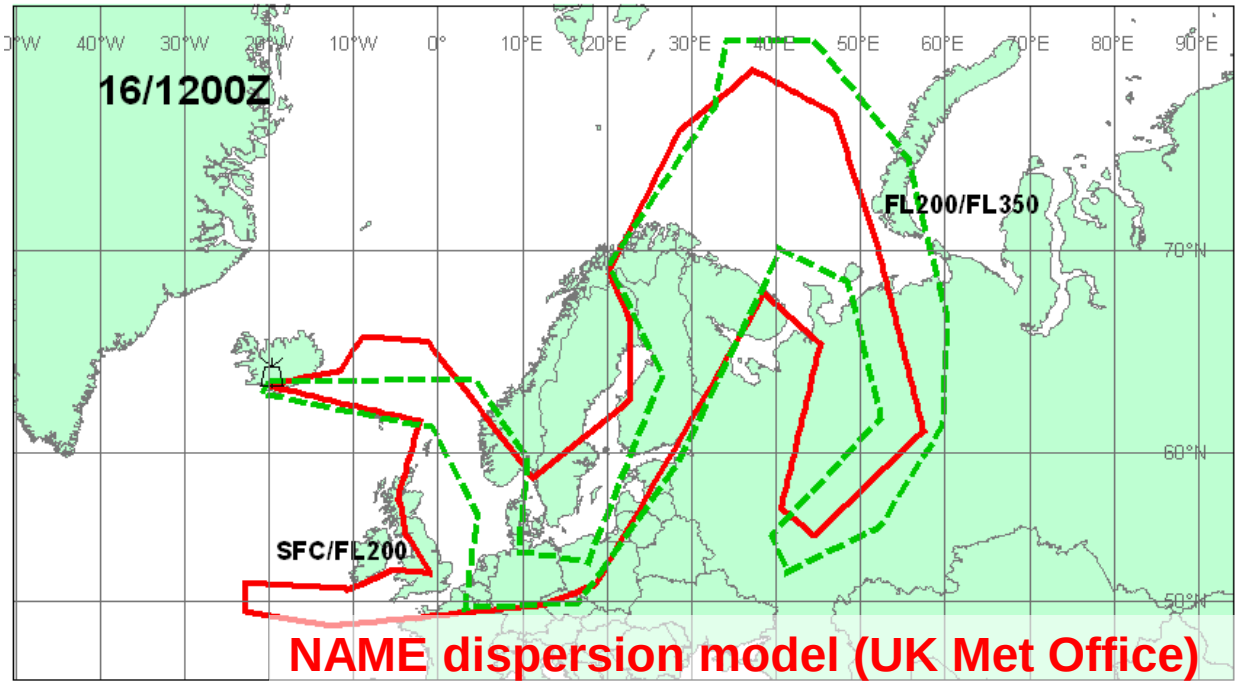
Volcanic Ash Advisory (VAA) and OMI AI – April 16

VA ADVISORY
DTG: 20100416/0600Z
VAAC: LONDON
VOLCANO:
EYJAFJALLAJOKULL
PSN: N6338 W01937
AREA: ICELAND

SUMMIT ELEV: 1666M
ADVISORY NR: 2010/009
INFO SOURCE: ICELAND MET OFF
AVIATION COLOUR CODE: RED
ERUPTION DETAILS: SIGNIFICANT
CONTINUING, REACHING FL180.

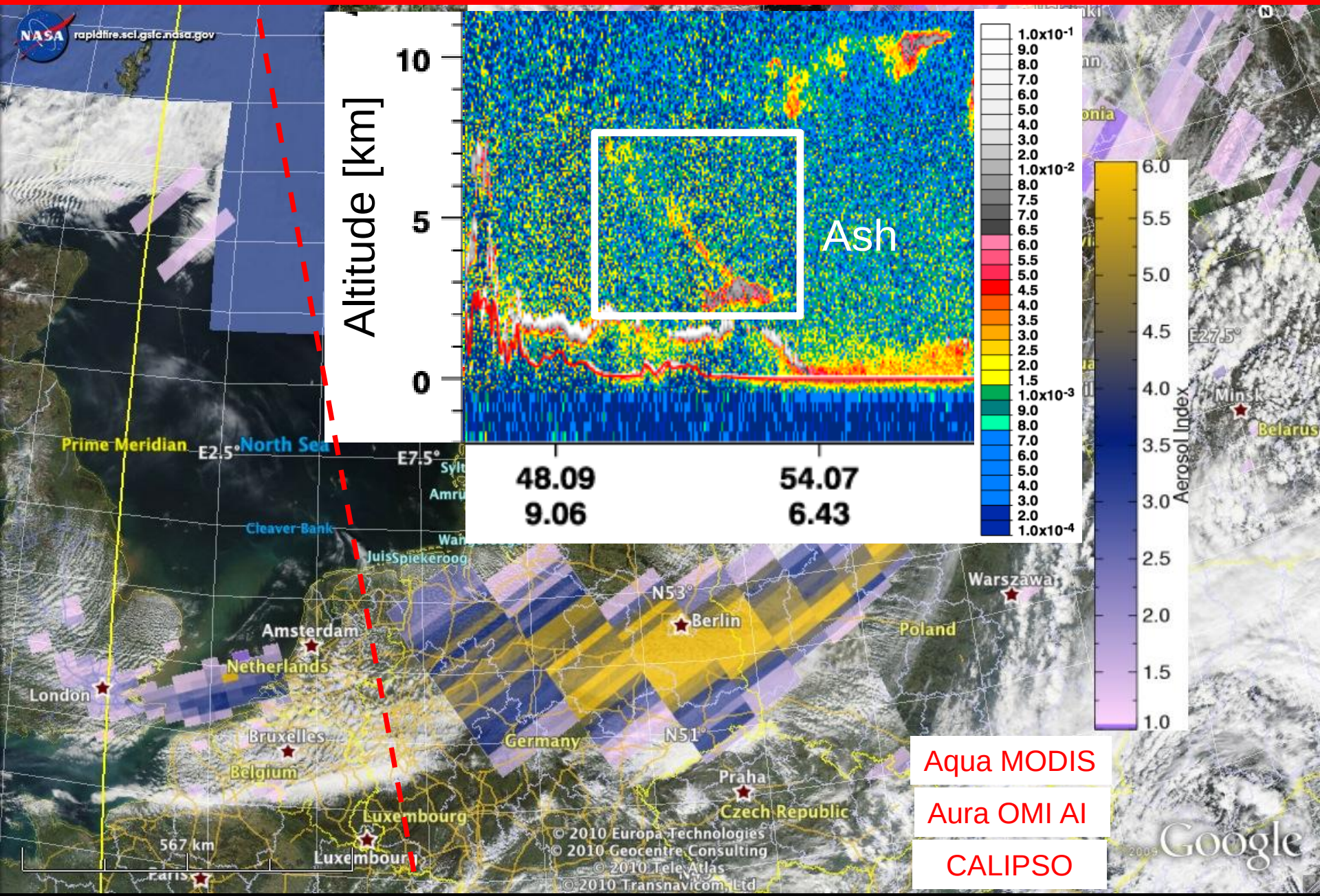
RMK: ASH CONCENTRATIONS WIT
UNKNOWN. NO SIGNIFICANT ASH
NXT ADVISORY: 20100416/1200Z





NAME dispersion model (UK Met Office)

A-Train measurements – April 16



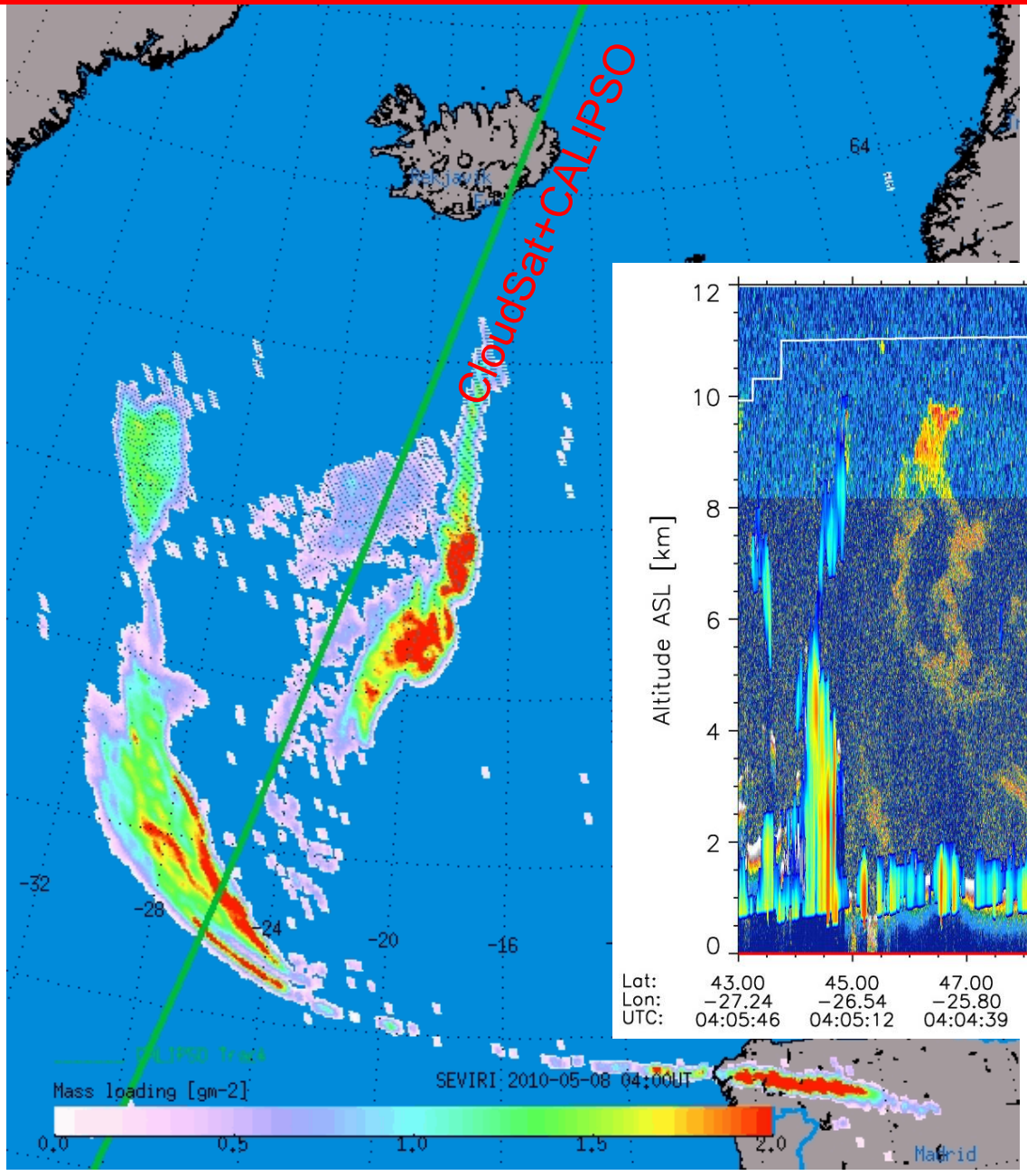
Eyjafjallajökull: ‘strong’ and ‘weak’ eruption plumes

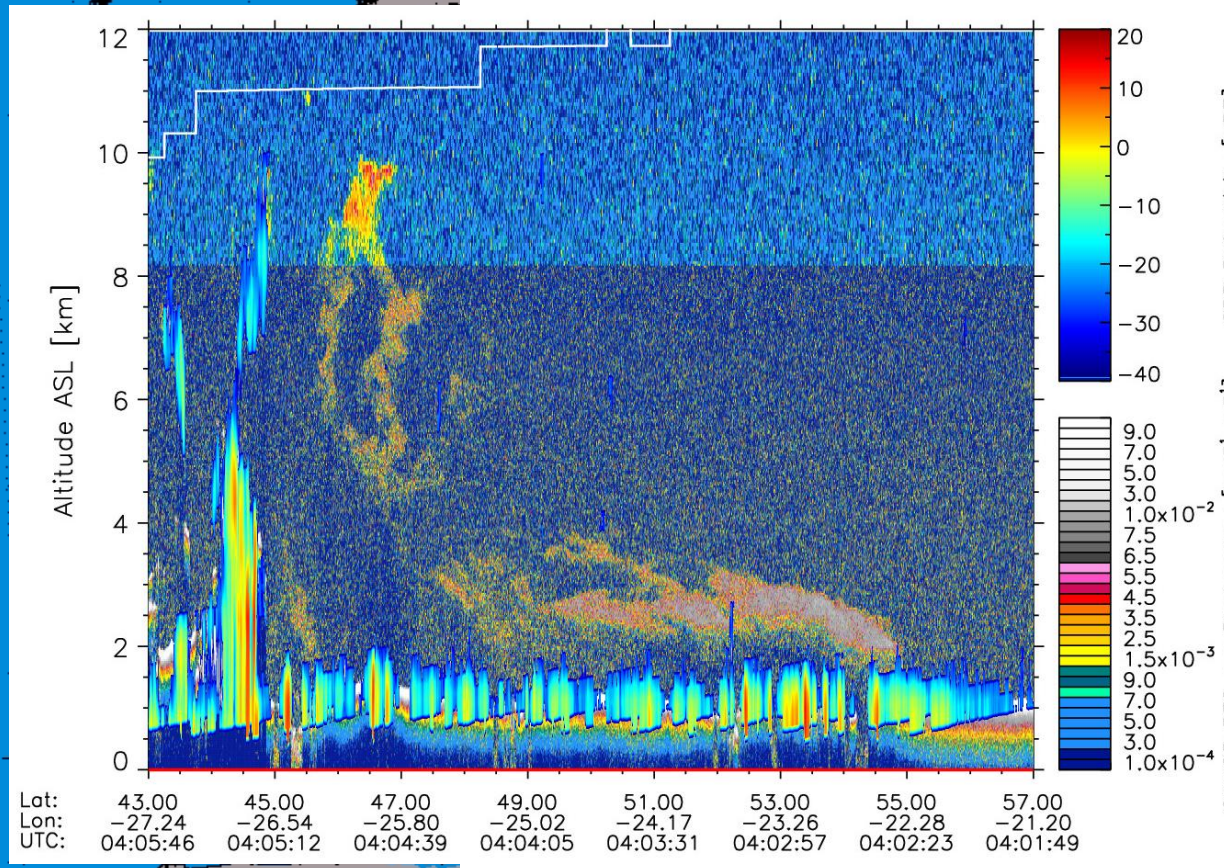
$$H = 1.67Q^{0.259}$$

- Empirical relationship of mass eruption rate (Q) to plume height (H) for ‘**strong**’ plumes
- Assumes a single injection height
- Does not account for environmental factors (e.g., wind, humidity), gravity current intrusions etc.

- When does advection-diffusion take over?
- -> Initialize models with accurate vertical profile information

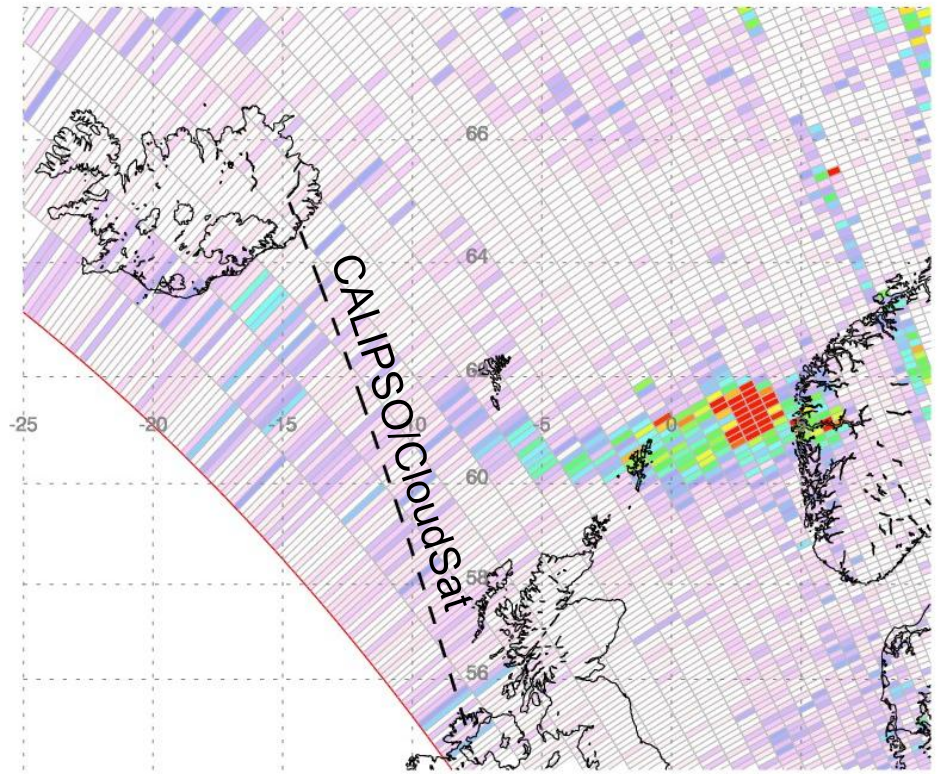
A-Train observations of Eyjafjallajökull plume – May 8, 2010



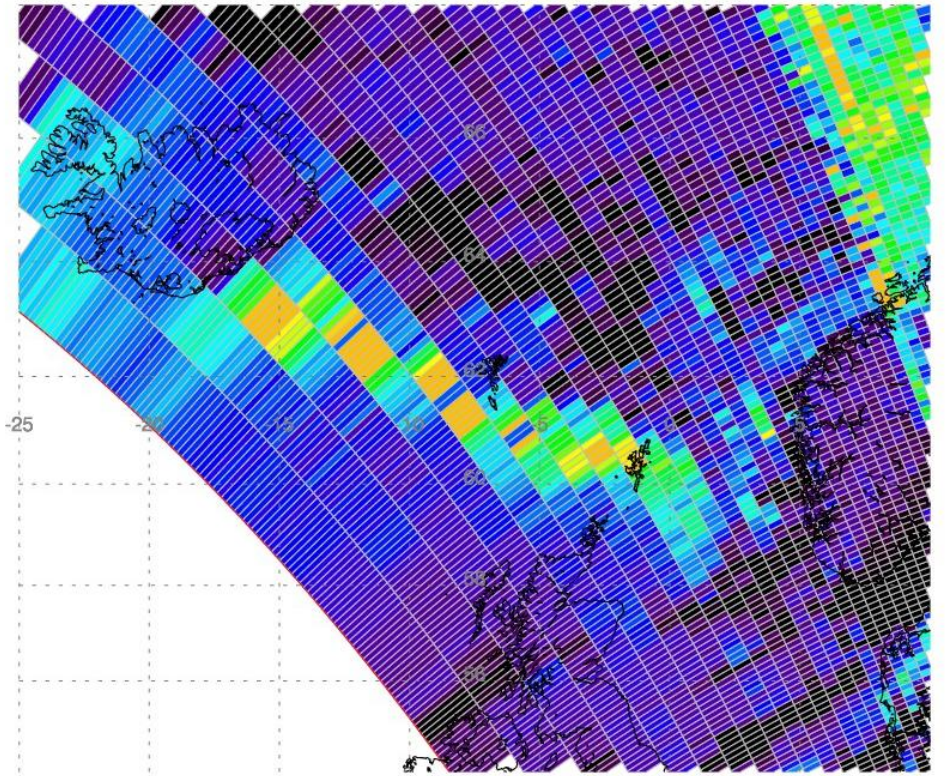


- Ash concentration = mass loading/thickness
- Thickness from CALIOP
- Typical concentrations were ~2-4 mg m^{-3}

Eyjafjallajökull eruption plume – April 15, 2010



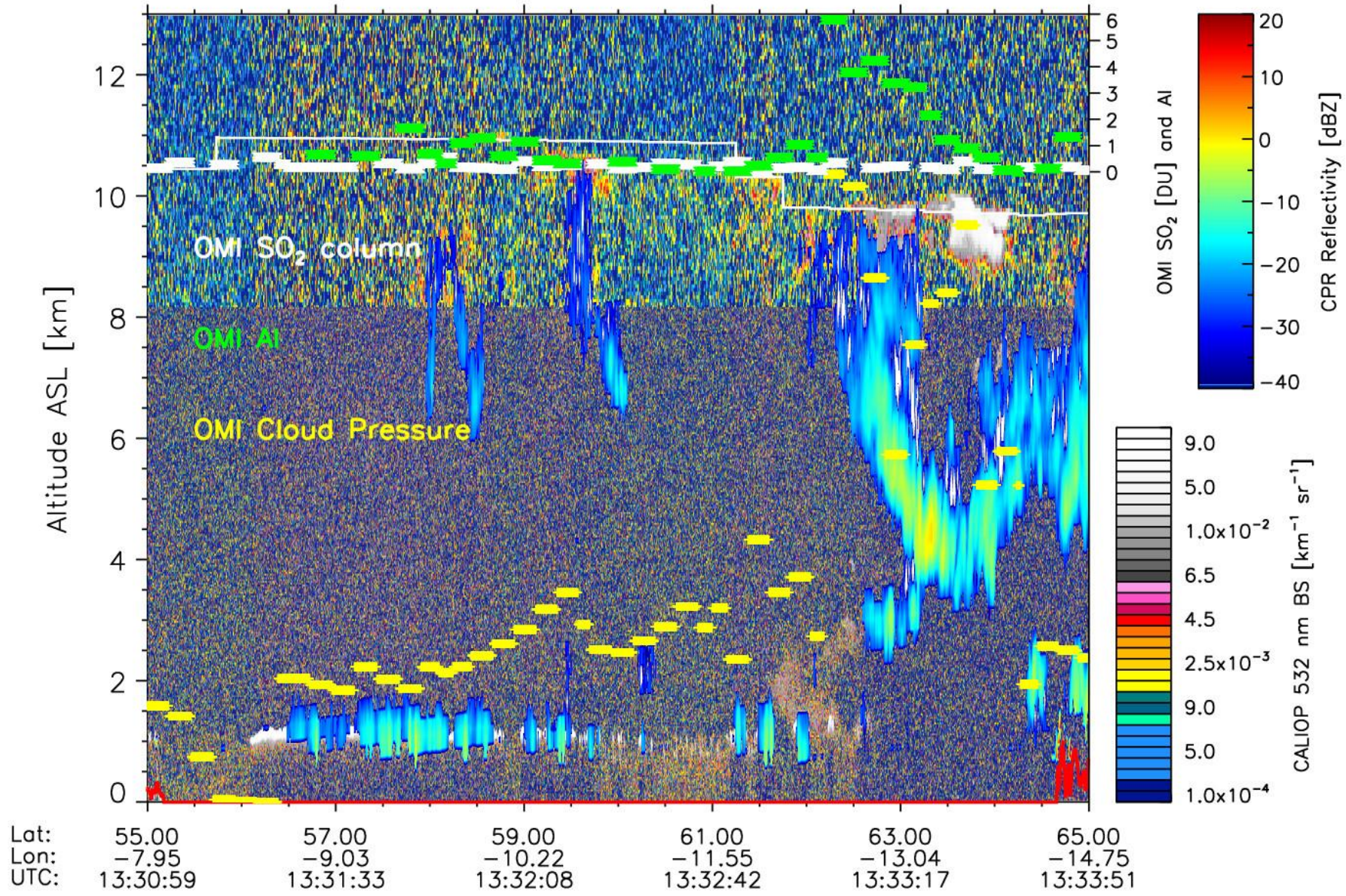
OMI SO_2 column



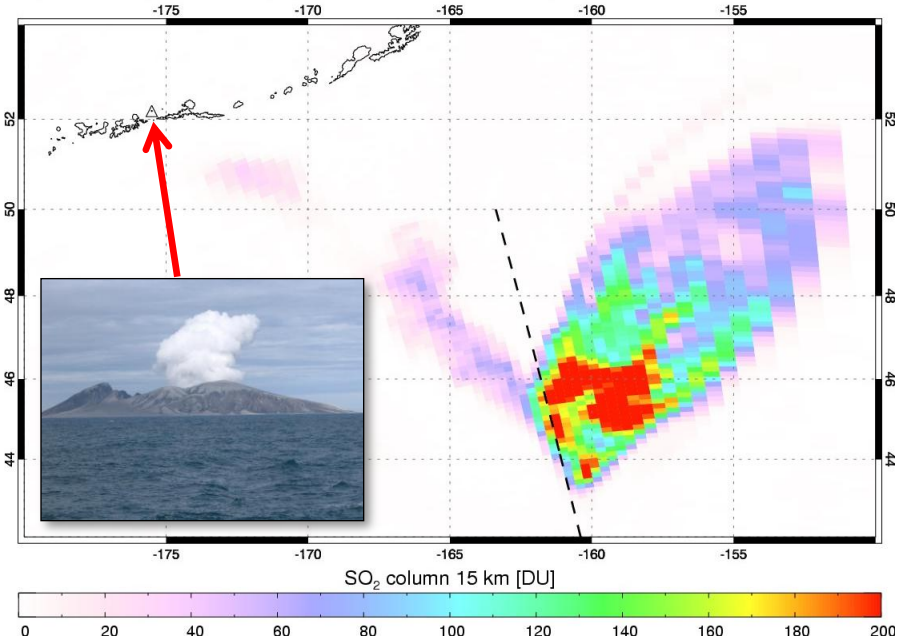
OMI Cloud Pressure

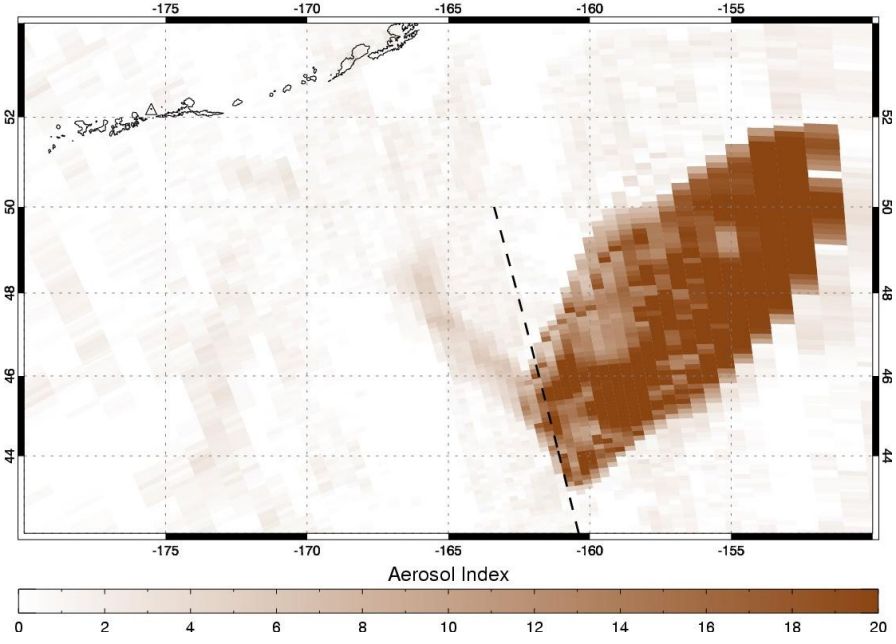
- NB: OMI row anomaly coincides with CALIPSO/CloudSat track

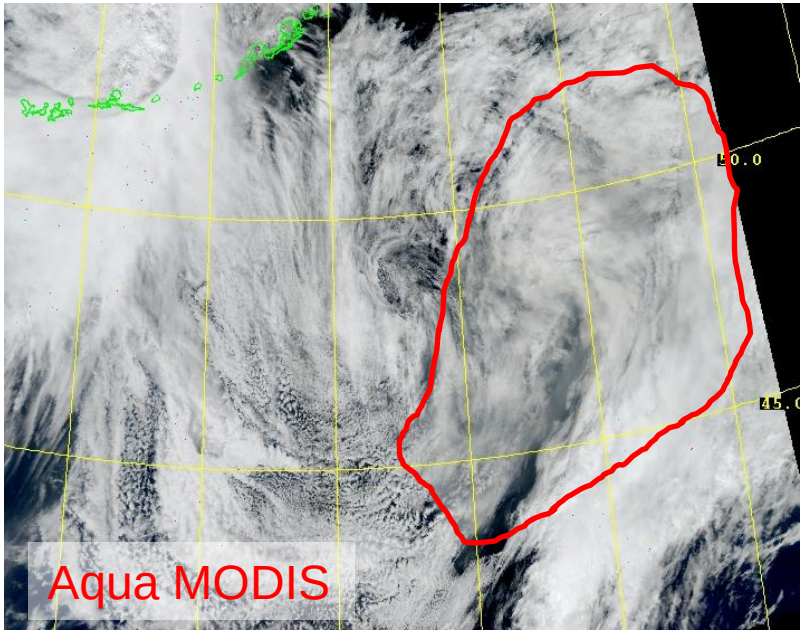
CALIPSO + CloudSat + OMI: April 15, 2010



A-Train observations: Kasatochi, August 9, 2008





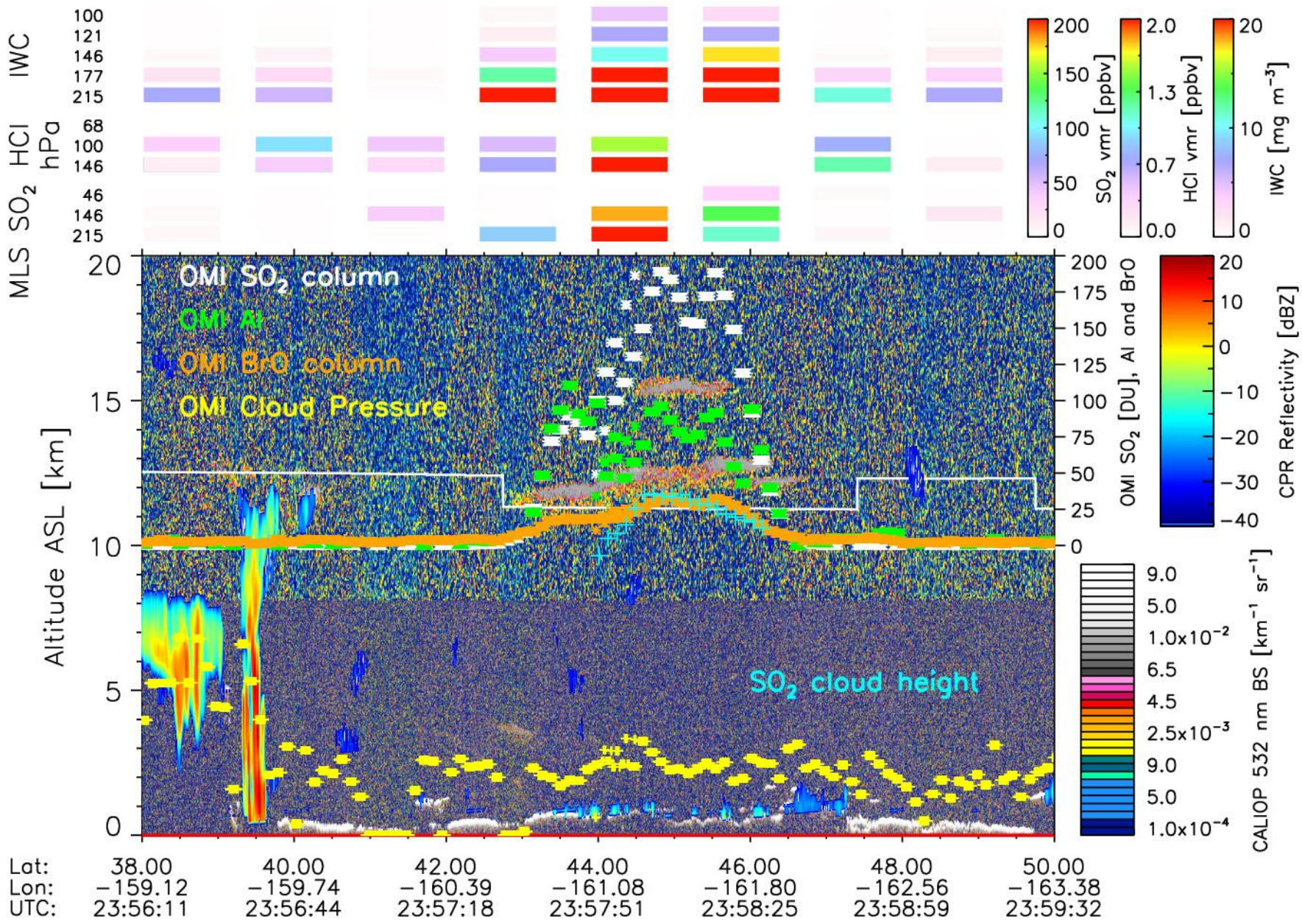


- Largest volcanic SO_2 emission since 1991 (~2 Tg)
- Negligible climate impact

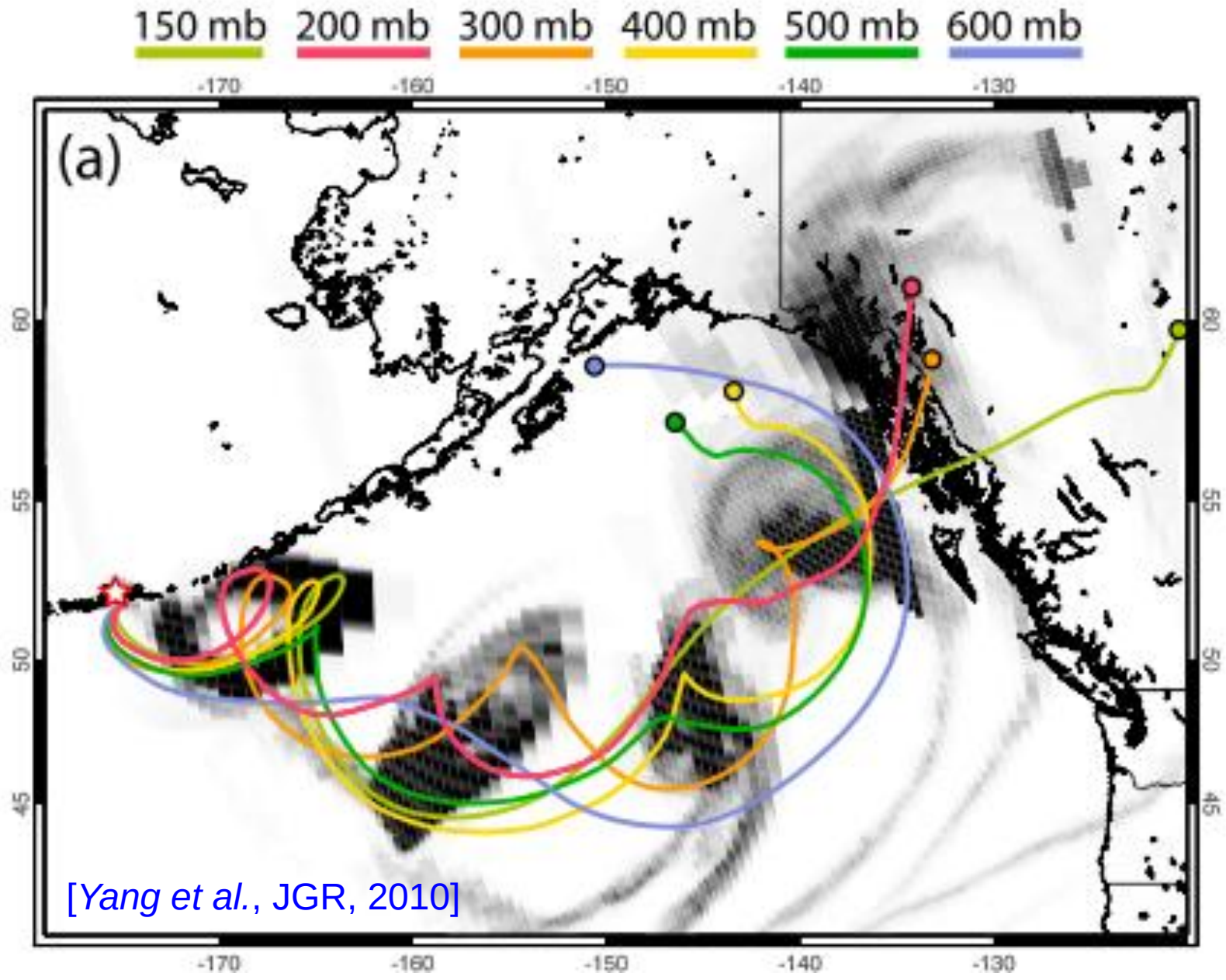
JGR Special issue

http://www.agu.org/journals/jd/special_sections.shtml?collectionCode=VOLCANOES1&journalCode=JD

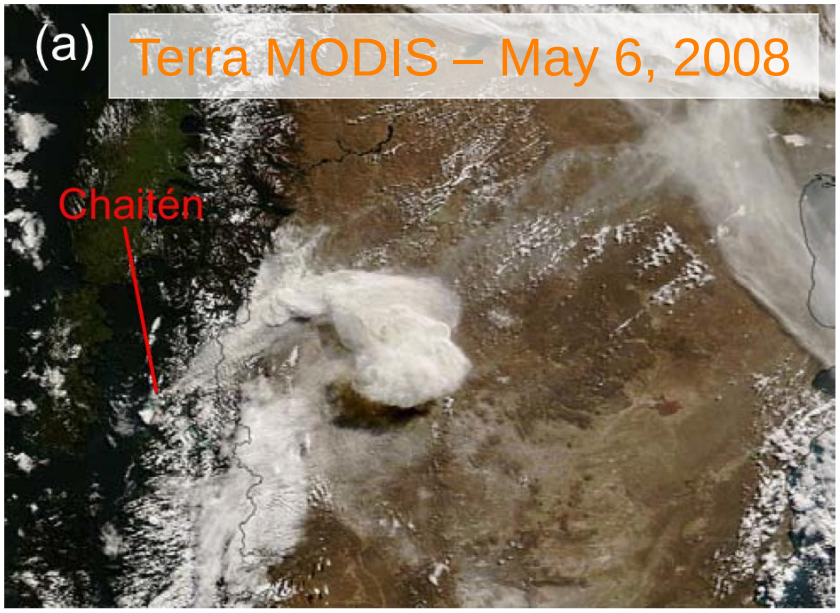
A-Train observations: Kasatochi, August 9, 2008



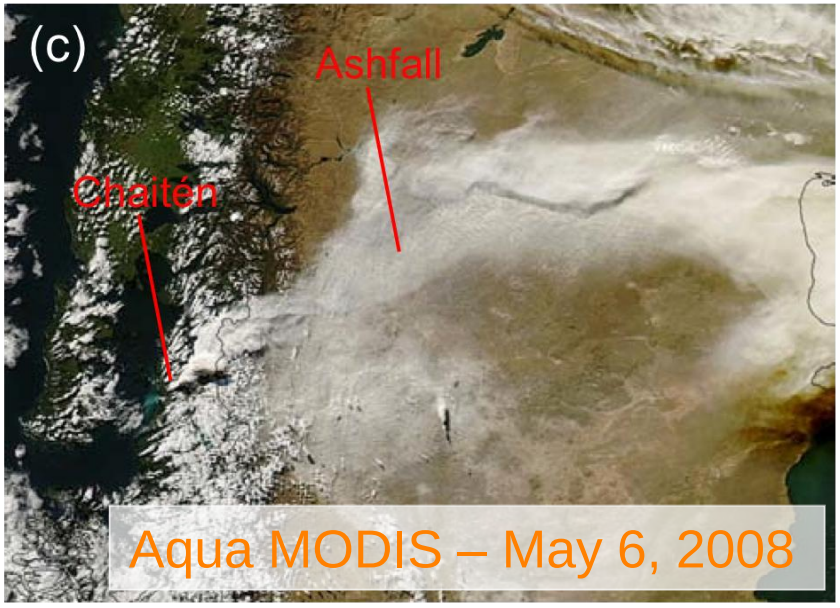
Forward trajectories for the Kasatochi volcanic cloud



A-Train observations: Chaitén (Chile), May 2008

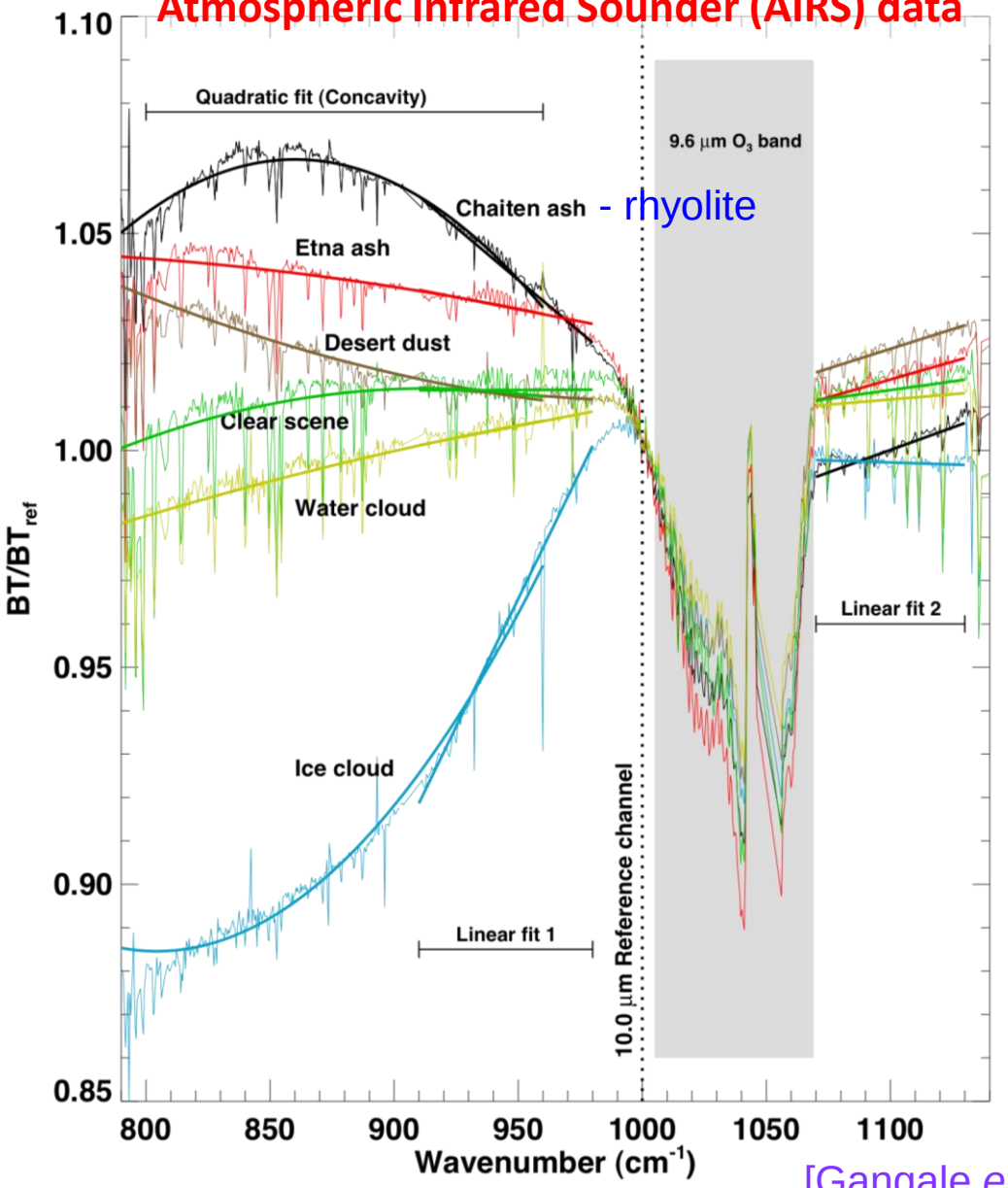


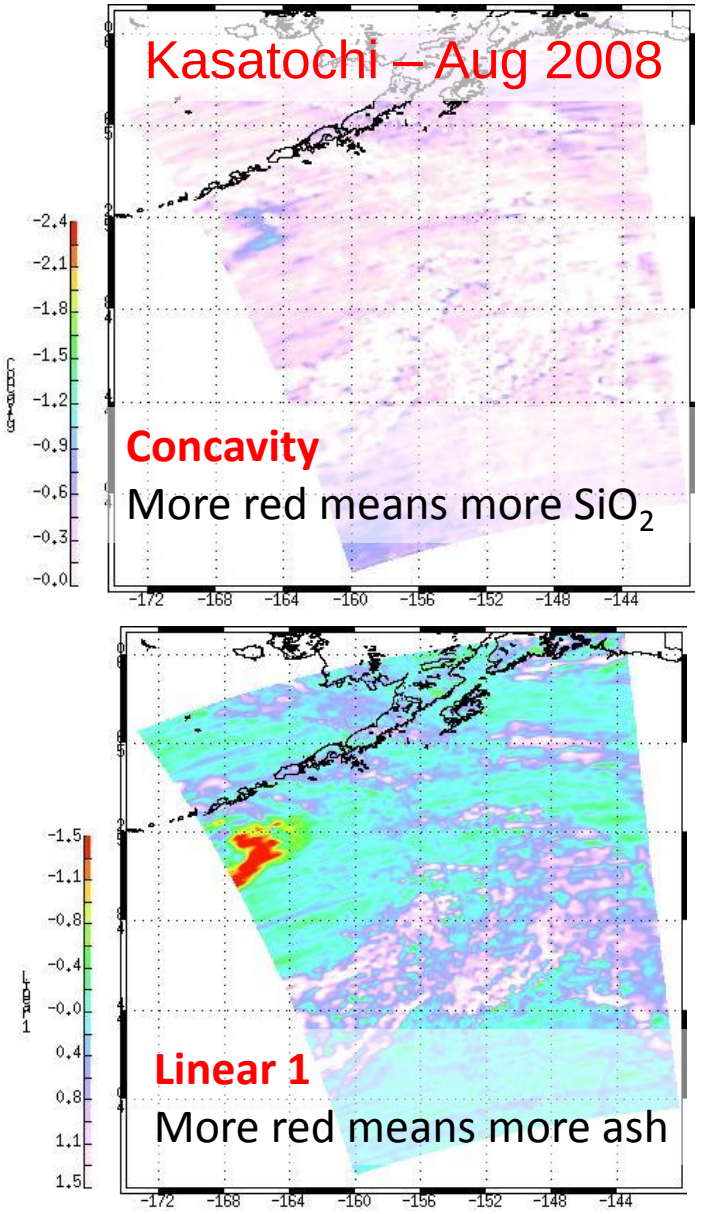
[Carn *et al.*, EOS, 2009]



- Eruption at ~0800 local time on 6 May
- High wind shear environment

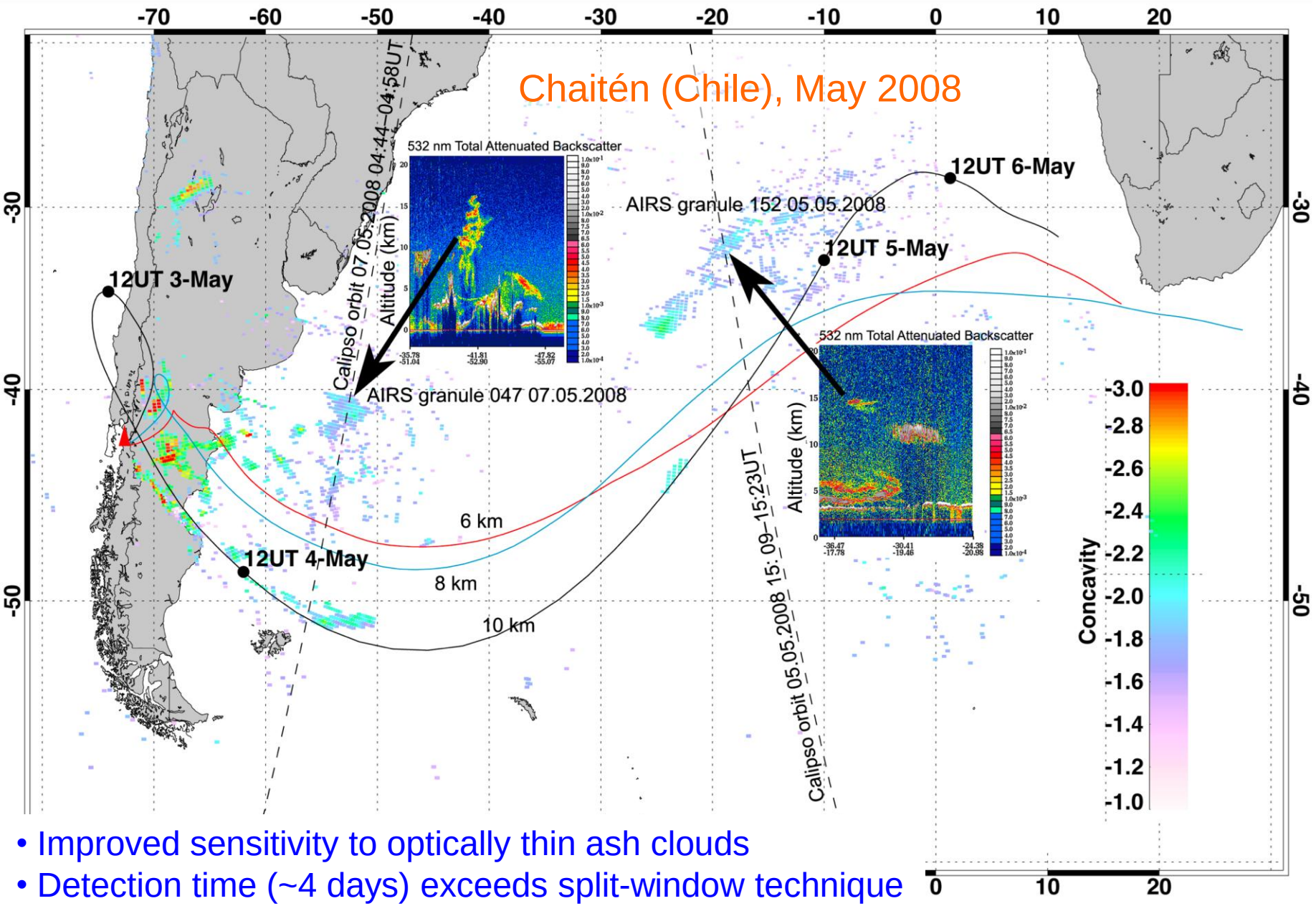
IR ash composition retrievals – the 'Concavity' signature





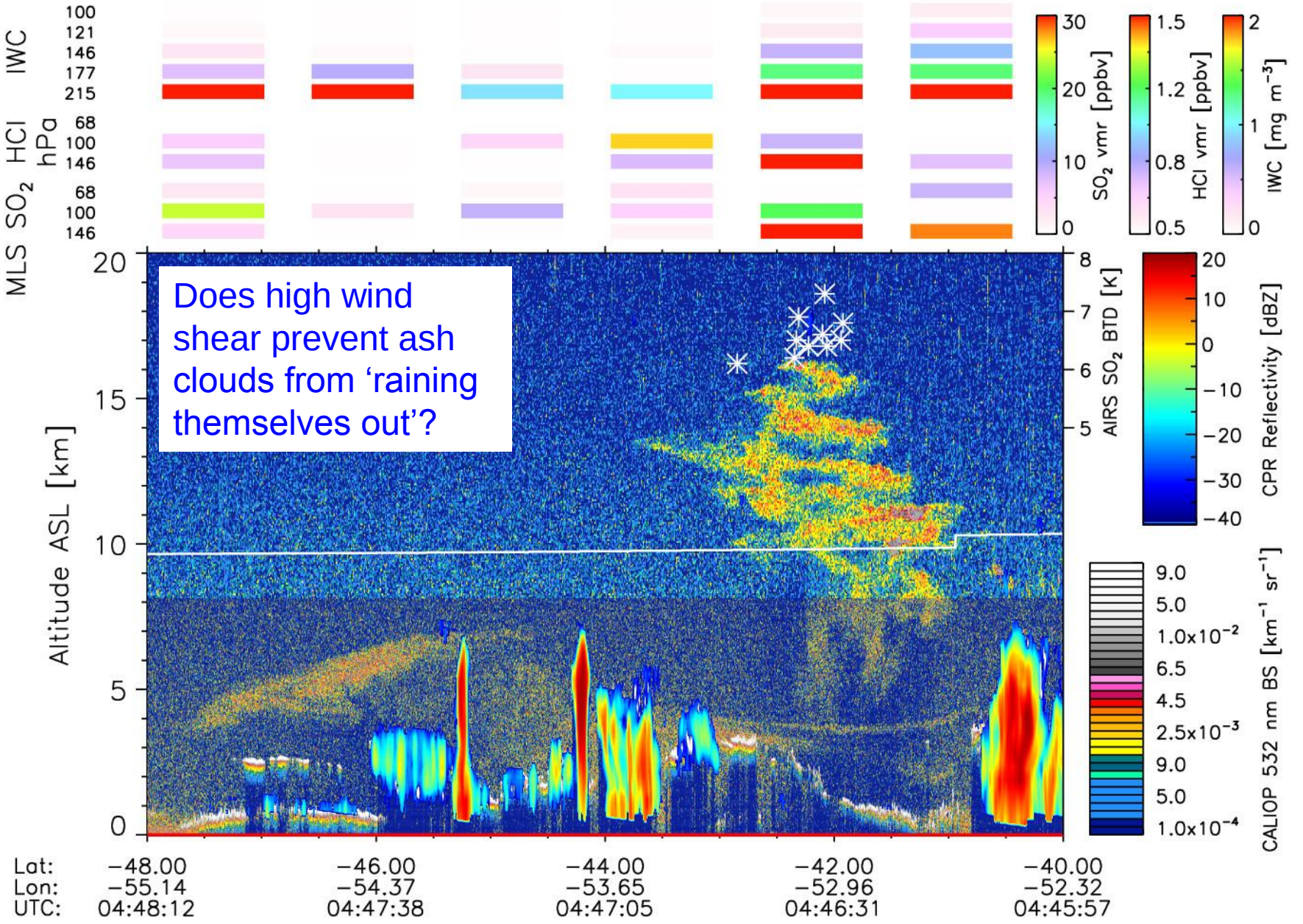
[Gangale *et al.*, RSE, 2009]

Volcanic ash tracking with the AIRS concavity algorithm

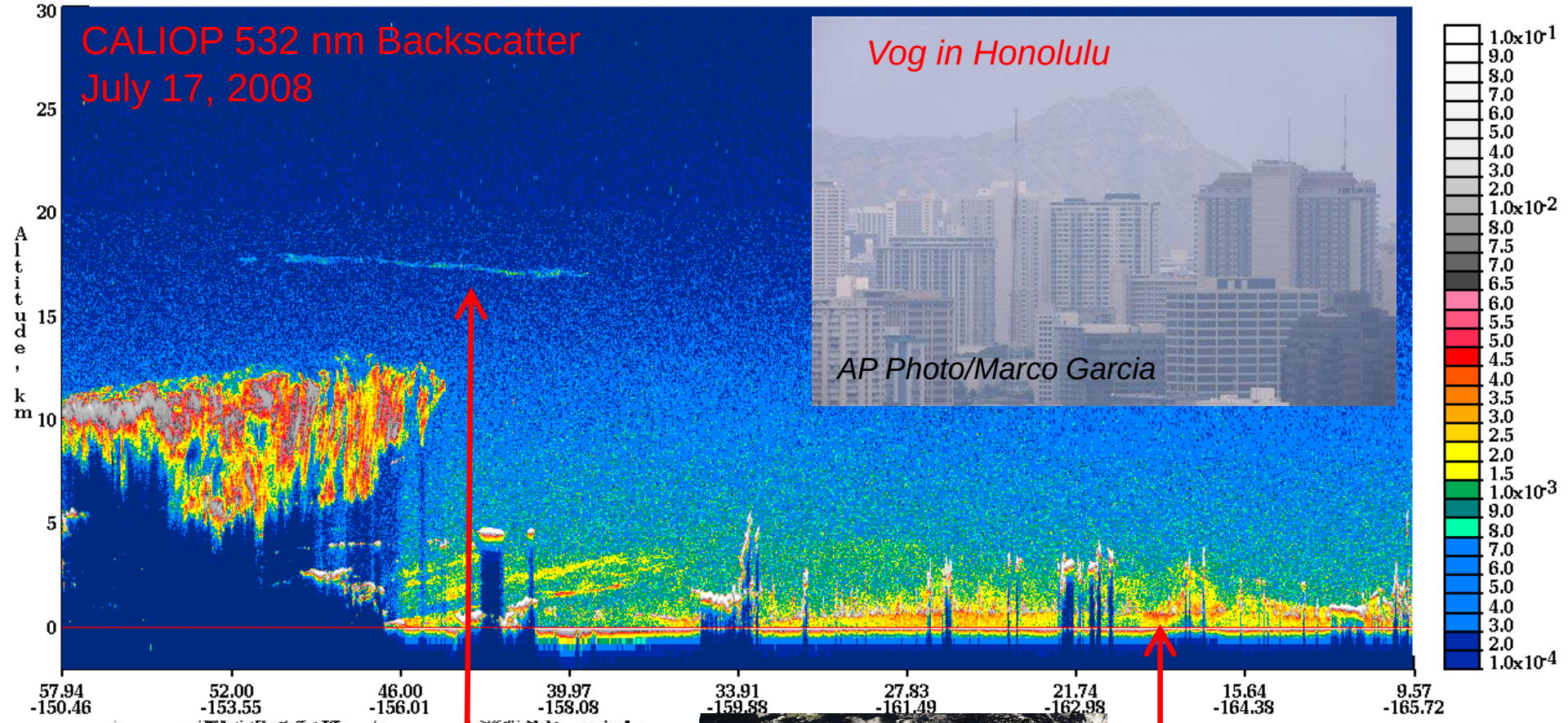


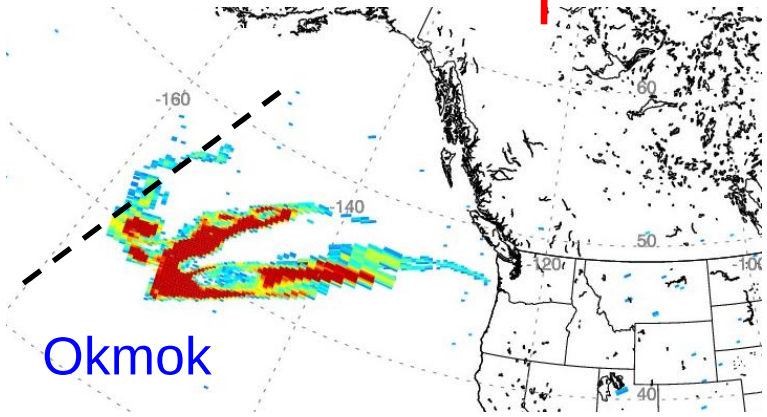
- Improved sensitivity to optically thin ash clouds
- Detection time (~4 days) exceeds split-window technique

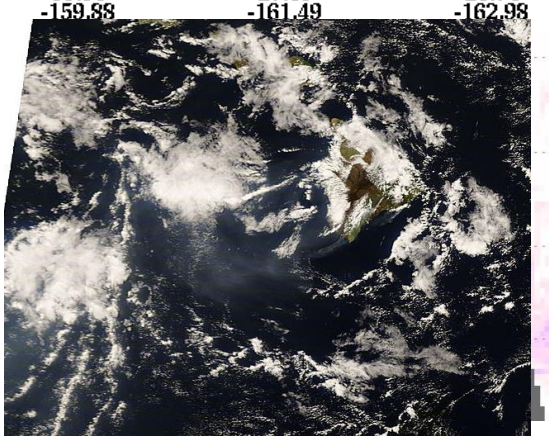
A-Train observations: Chaitén (Chile), May 7, 2008

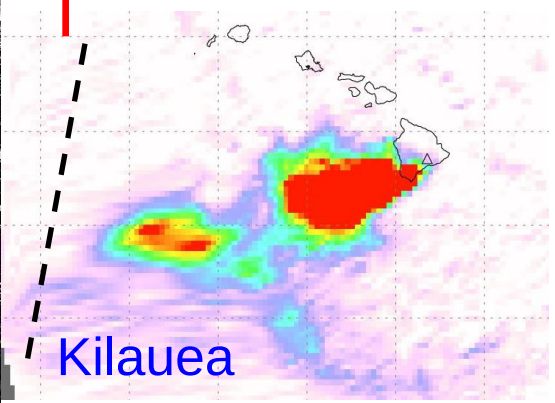


Monitoring tropospheric volcanic plumes with CALIPSO



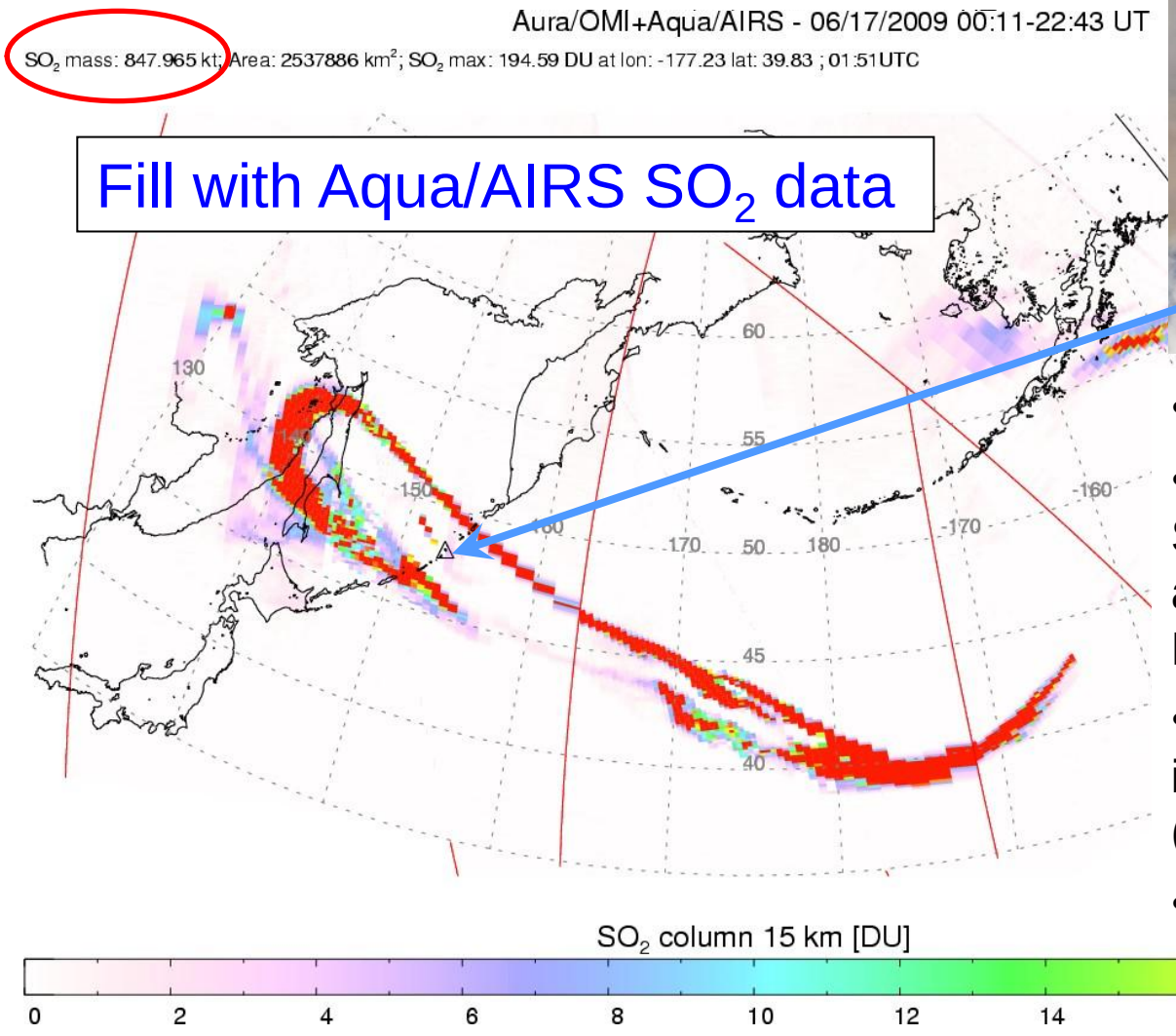






Sarychev Peak (Kurile Is) eruption

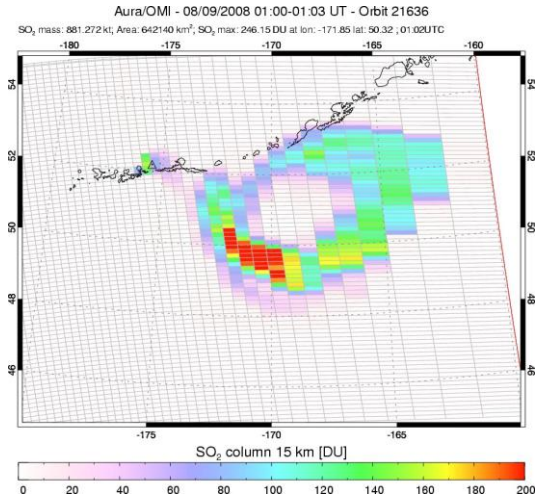
Astronaut photo from ISS, 14 June



- Previous eruptions in 1986-89
- 2nd large NH stratospheric SO_2 injection (≥1 Tg) in a year, after the August 2008 Kasatochi eruption (Aleutian Is)
- Timing near summer solstice increases aerosol radiative (cooling) effect
- Major disruption to aviation

- A-Train synergy compensates for data gap and improves SO_2 loading measurements

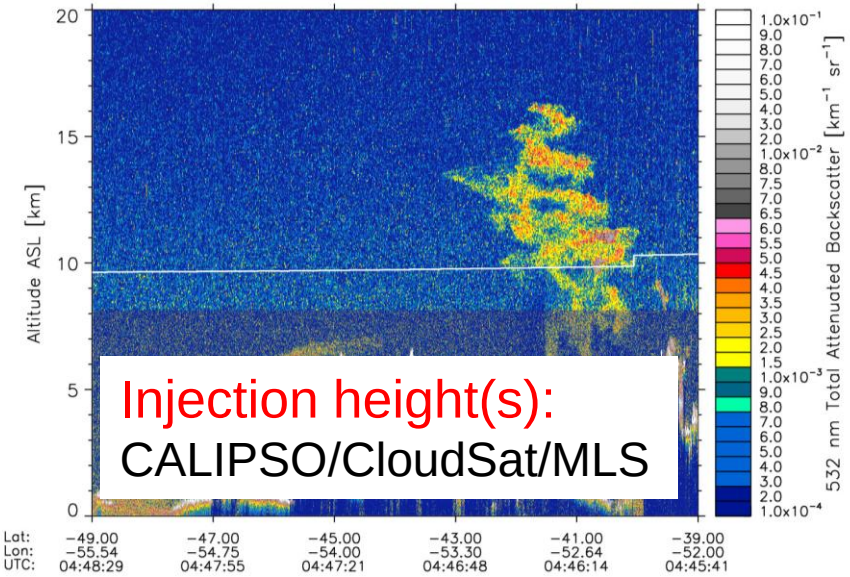
Hypothetical A-Train eruption monitoring system



Key issues:

Data latency

Spatial coverage

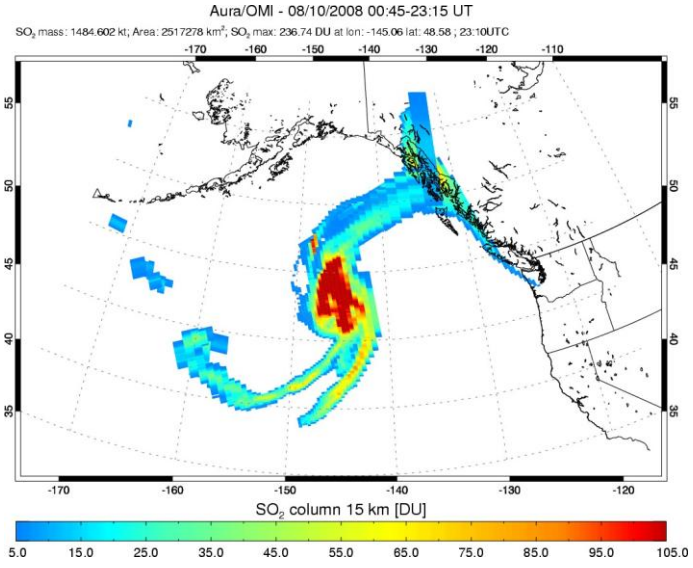


Injection height(s):

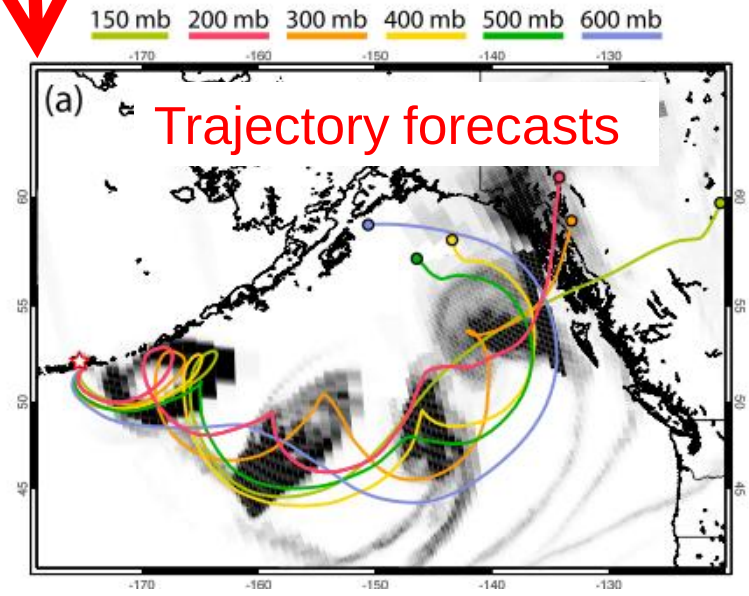
CALIPSO/CloudSat/MLS

Eruption detection:

SO_2 (OMI, AIRS); Thermal IR (MODIS)



Compare with SO_2/ash maps



Summary

- The A-Train is providing unprecedented observations of the vertical distribution of trace gases, aerosols and hydrometeors in volcanic clouds
- New insights into ashfall processes and stratospheric aerosol evolution in volcanic clouds are anticipated (*see talk by Mike Fromm*)
- Measurements of ash cloud altitude and thickness (e.g., by CALIPSO) are of prime importance for aviation hazard mitigation
- Currently, data latency of most A-Train products (and spatial coverage of the active sensors) is the main impediment to operational application for aviation hazard mitigation
- The A-Train greatly facilitates validation/intercomparison of satellite data products (e.g., SO_2 column measurements)

Acknowledgments: